Road lighting for pedestrian reassurance: consideration of methods and new metrics

A thesis submitted to the University of Sheffield for the degree of

Doctor of Philosophy

By

Aleksandra Liachenko Monteiro

School of Architecture

University of Sheffield

February 2021

ABSTRACT

One reason for installing road lighting in subsidiary roads is to enhance pedestrian reassurance after dark. Low reassurance has been associated with poor mental health, social isolation and lower active walking. However, despite numerous studies, it remains unclear if there are optimal lighting characteristics for pedestrian reassurance.

Two field studies were carried out in the city of Sheffield in the UK. Field study 1 was designed to examine the day-dark approach proposed by Boyce et al. 2000, which uses evaluations of reassurance in the daytime as well as after dark, rather than after-dark only. Thus, this study had 24 participants, rating 10 test locations in daytime and after-dark, using a survey. It also considered the development of a composite evaluation item to characterise reassurance rather than rely on the response to a single question.

The results of field study 1 suggested that reassurance was better characterised by minimum illuminance and uniformity than by mean illuminance, the usually considered metric, but that was not an apriori hypothesis of field study 1. Therefore, Field study 2 was carried out with an expanded sample (35 participants) and a set of locations (16 roads) to test that hypothesis and also to consider the association between reassurance and three types of illuminances referred to in lighting guidance - horizontal, hemispherical, and semi-cylindrical. Results of Field Study 2 suggest the minimum horizontal illuminance and hemispherical mean illuminance are more relevant than horizontal mean illuminance for pedestrian reassurance.

Finally, some consideration to methodological matters is given, such as the impact in findings of asking participants to imagine after-dark settings and the validity of subjective assessments of lighting. Responses to an item regarding the perceived risk at night were analysed. These analyses suggested that asking participants to imagine an after-dark scenario might promote lower perceptions of safety. Also, the association of subjective evaluations of the lighting were analysed against the lighting metrics and reassurance appraisals resulting from study 1 and 2. Findings suggest that the perceived quality of lighting, in both studies, is associated with the recorded significant illuminances of each study.

ACKNOWLEDGEMENTS

I would like to thank my supervisor, Prof. Steve Fotios, not only for the opportunity to undertake this doctorate, but also the support in building-up the confidence to present at conferences and to finish this work.

To Dr. Jim Uttley I would like to thank for his immense academic generosity, ethical nature and statistics wizardry. Then, I would like to thank all my departmental colleagues for sharing their kindness with me translated into biscuits, conversations and some laugh in-between academic research. On that note, a special thanks to Khalid Hamoodh who kindly accepted to endure numerous hours of lighting measurements out in the cold. I would also like to thank Dr. Chris Cheal who put together the most functional and portable lighting apparatus, which played a central role in this research.

I must also thank Dr. Benedetta Mattoni, Ana Gonçalves, Maria Sklavou, Sofia Gamez and Olivia Trujillo for their academic support and invaluable friendship. Each of you made my journey much more meaningful!

To my parents I thank the encouragement and the availability to often listen about stuff they had no interest in. Subsequently, I would like to thank my siblings, Madalena Monteiro and Daniel Monteiro, and my cousins Luis Abreu Lima and Jose Monteiro, who believed in me and for me when I did not.

Finally, I thank all participants who adventured themselves in these long walks out in the cold, and at least once in the dark. I am thankful for your time and attentiveness.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF EQUATIONS

GLOSSARY OF KEY CONCEPTS

Average illuminance

refers to the arithmetic mean of 10 measurement points in the longitudinal direction between luminaires, except when the distance between the luminaires is above 30 meters; in this case it refers to the average of equally distanced points at a maximum of 3 meters between each other (BS EN 13201-3:2015).

Fear of crime

is a multidimensional phenomenon that encompasses a perception, emotional response and behavioural reaction to potential crime and victimisation, safety, and risk.

Illuminance

is the light emitted by a luminaire that falls on a surface, on the surface direction (BS EN 12665:2018). In this thesis this could be in the horizontal, hemispherical and semi-cylindrical surface direction.

Item

refers to a survey question.

Lux

is the standardised unit of measurement of illuminance.

Minimum illuminance

is a metric that refers to the lowest illuminance value recorded in the 10 measurement points in the longitudinal direction between luminaires.

Pedestrian

a road user walking rather than travelling in a vehicle.

Reassurance

is considered as the opposing concept to fear of crime, referring to the confidence to walk outside in the context of this thesis.

Uniformity

is a lighting metric that refers to the ratio of minimum illuminance to the average illuminance in this thesis. Other studies calculated uniformity as the ratio of the minimum illuminance to the maximum illuminance.

Chapter 1. Road lighting for pedestrians

1.1. Introduction to road lighting

Road lighting is an artificial mean of providing luminance in an urban setting. This is done by placing several columns with lamps on the pavement along the road to illuminate it. This allows daily life to be extended past daytime light hours. After dark, the ability to see is otherwise impaired, as the human eye relies upon the existence of light to see (Boyce 2014). Figure 1 shows a comparison of a picture taken in Sheffield in 2016 in the daytime and one in the after dark of the same location.

Figure 1. Photograph taken in 2016 of the same road, in Sheffield, in daytime and after-dark conditions

Road lighting allows the safer movement of drivers, pedestrians, and cyclists after-dark. This is because it facilitates the visibility of people and objects that otherwise during after dark would not be possible.

Due to the different needs of the urban tissue users, the desired effect of lighting varies. For example, drivers need to detect and recognise objects and other people at a sufficient distance in order to reduce the speed or stop the vehicle avoiding collision, while pedestrians need to be able to make interpersonal judgements, identify obstacles and feel safe from harm when walking. Fotios, Yang and Cheal (2015) have confirmed that pedestrians mainly examine the path and other pedestrians when walking outdoors. The authors investigated the critical visual tasks of pedestrians using eye-tracking technology concluding that participants fixated more on the path and other people suggesting that detection of hazards on the pavement and interpersonal assessment is a critical task for pedestrians. Furthermore, road lighting is also said to aid in deterring criminality due to increased visibility of the surroundings enabling recognition of criminal activity (Piroozfar et al. 2019).

Road lighting is classified into three categories: M lighting class, C lighting class and P lighting class (CIE 115:2010). These classes are selected according to the function of the road and traffic volume, among other factors. The M-class is used for motorways or other high motorised traffic routes where drivers' visual tasks are crucial. The C-class refers to conflict areas such as crossings or any other urban areas where there might be an intersection between road users. The P-class comprises the roads where pedestrian tasks are of higher importance, namely residential roads. Due to the nature of the present research, this chapter focuses on the road lighting for pedestrians, thus P-class standards, and the lighting of residential areas. Each of these broad categories comprises several lighting classes characterised by specific lighting design criteria. A lighting class is attributed to a road according to several factors, such as volume of traffic or speed.

Thus, it is fundamental to pinpoint the purposes of road lighting for pedestrian users. According to the CIE, the International Commission on Illumination, the purposes of road lighting in urban areas are (CIE 206-2014):

(1) To improve the appearance of the surroundings,
(2) To assist orientation in space,
(3) To promote a sense of safety,
(4) To identify potential hazards, and,
(5) To recognise other road users.

1.2. Lighting design for pedestrians and residential roads

Residential roads are considered a pedestrian and low speed area, thus a P lighting class. In the UK, the document CEN/TR 13201-1:2014 specifies how these lighting classes are to be determined. Pedestrian and low speed areas are defined as "*relevant area [sic] reserved for use by people on foot or using bicycle [sic], and drivers of motorised vehicles at low speed ($\leqslant$ 40 km/h)*" (CEN/TR 13201-1:2014, p. 6). This technical report describes the selection method as outlined in the CIE 115:2010 technical report but provides supplementary information on the maximum and the average within an acceptable range of minima and maxima illuminances. Classes are defined by weighting the given parameters to then find the appropriate P lighting class number that ranges from 1 to 6. These parameters consider travel speed, traffic composition, parked vehicles, the existence of other ambient light sources, facial recognition needs, and the influx intensity of users to the road. For each P-lighting class, the lighting levels are defined in several different metrics (Table 1).

The BS EN 13201-2:2015 establishes that the average horizontal illuminance ($\bar{E}$), the minimum horizontal illuminance (Emin), the average hemispherical illuminance ($\bar{E}$hs) and the overall uniformity of the hemispherical illuminance (Uo) are to be considered for P lighting classes. Illuminance is the light emitted by a luminaire that falls on a surface, on the surface direction (BS EN 12665:2018). For example, horizontal illuminance refers to the light that falls on the road, whilst semi-cylindrical is mainly addressed for the benefit of interpersonal judgements and facial recognition. Thus, illuminance is the objective metric for the subjective brightness concept commonly used.

Table 1. Lighting levels for P-class roads lighting design according to BS EN 13201-2:2015

Illuminances (lux)	Horizontal		Vertical^a	Semi-cylindrical^a	Hemispherical		
Class	$\bar{E}$	E_{min}	$E_{\text{v,min}}$	$E_{\text{sc,min}}$	Class	$\bar{E}_{\text{hs}}$	U_{o}
P1	15.00	3.0	5.0	5.0	HS1	5.00	0.15
P2	10.00	2.0	3.0	2.0	HS2	2.50	0.15
P3	7.50	1.5	2.5	1.5	HS3	1.00	0.15
P4	5.00	1.0	1.5	1.0	HS4	Performance not determined	
P5	3.00	0.5	1.0	0.6			
P6	2.00	0.4	0.6	0.2			
P7	Performance not determined						

[a] Parameters to consider if facial recognition is necessary

While these are the lighting metrics and levels currently adopted in the UK, these might not be representative of pedestrian needs (section 1.2.). Fotios (2019) points out that if the parameters are not addressing the needs of pedestrians, lighting conditions are likely not to be appropriate or optimal. If pedestrian needs are related to safety and visual tasks such as obstacle detection and facial recognition, the P-lighting class parameters are unlikely to address them by assessing the number of vehicles parked or traffic composition. If standards state that pedestrians are the main users of residential roads, then these should consider fundamentally the needs of these users.

The shared urban fabric must be considered but bearing in mind the fundamental users of each area. Otherwise, there might be a considerable energetic waste and unfulfilled needs.

1.2.1. From the source to the impact of road lighting

A fundamental component of road lighting is the lighting source. Lighting installations might use (1) Fluorescent lighting, (2) Low-Pressure Sodium (LPS), (3) High-Pressure Sodium (HPS), (4) Metal Halide and (5) Light-emitting diode lighting (LED), among others. These vary in the Spectral Power Distribution (SPD). Spectral Power Distribution refers to the power of radiation dispersion within a wavelength spectrum of 380 to 780nm. This is the wavelength spectrum visible to the human visual system. This radiation is observed in terms of brightness and colour. Two lighting installations might display the same photometric values but present different perceived colour due to the combination of received light in the visual system receptors (Boyce 2014).

The photoreceptors are divided into two types - rods and cones, that perform differently depending on the lighting conditions (Boyce 2014). Rods allow the human eye to perform under darkness and are responsible for the perception of shadows, thus contrast (scotopic vision). On the other hand, cones allow colour vision under well-lit conditions (photopic vision). Road lighting aims to install lighting that performs in a mid-term, stimulating both scotopic and photopic vision, thus facilitating the mesopic vision. In BS 5489-1:2020, the Scotopic/Photopic ratio (S/P ratio) is acknowledged as relevant for visual performance due to this delicate balance of the visual system under different lighting conditions.

Knight (2010) investigated the effect of the lamp spectrum on the perception of safety in three different European countries. For this study, over 300 participants evaluated the same poster image under different spectral power distributions. Metal Halide and High-Pressure Sodium lamps were used, ranging between 5-15 lux in average vertical illuminance, but presenting differing CCT and CRI (Table 2). The participants had to indicate both the most reassuring and the brightest lighting condition. Conclusions showed that whiter light, thus presenting a higher Correlated Colour Temperature (Table 2), tends to enhance safety perceptions and the perception of brightness.

However, for road lighting design Correlated Colour Temperature (CCT), measured in Kelvin degrees (K), is more relevant. Low colour temperature (below

3200K) means a warmer orange or yellow appearance, while higher colour temperature (above 4000K) means a bluer perceived light. Different road lighting sources will present distinct lighting colour temperatures and a different Colour Rendering Index (Table 2). The Colour Rendering Index (CRI) is the guide to the quality of light, where 1 is monochromatic and 100 is approximate to the daylight quality. Thus, the CRI provides guidance to the quality of artificial light to disclose the colours of objects and surroundings compared to natural light.

Table 2. Light sources and correspondent estimated CCT and CRI (Boyce 2014)

Light source	CCT (K)	CRI
LPS	1700	-
HPS	1900-2500	19-83
Metal Halide	3000-6000	60-93
Compact Fluorescent	2700-6500	80-90
LED	2650-6500	40-85
Daylight	5000-6500	n/a

Although the present research does not focus on colour temperature, the test locations, later described, introduce different light sources at points. High colour rendering is said to facilitate facial recognition (BS EN 13201-2:2015) and thus, might produce an effect on safety appraisals and consequent behaviour. Bearing in mind that photopic vision is responsible for the perception of colour stimulated in higher lighting conditions, the relationship between the S/P ratio and the CCT is evident. Then, the subjective concept of brightness, as previously mentioned, is also dependant on these metrics.

Brightness is a relative evaluation because it is likely to vary according to personal characteristics such as age, eye colour, visual acuity, and even individual expectations of the light levels. Considering that brightness is a subjective judgement and might refer not only to the effective light level but also to the colour temperature perceived, this might have an effect on perceived safety. In a study on lighting in offices, whenever the light was brighter participant behaviour was motivated by an interpersonal regulation of behaviour (Steidle & Werth 2014). Interpersonal regulation of behaviour is relevant to the context of safety in public spaces, as this could provide a sense of guardianship of the urban tissue. That is to say, that increased perceived brightness could promote lawful behaviours and enhanced perceived safety.

Considerations over lighting sources and the spectral power distribution are relevant as these have energy efficiency implications. A road light has a cost for installation, energy consumption and maintenance. When choosing the light source local authorities must consider not only the national lighting standards but such practical considerations as the luminous efficacy, the correlated colour temperature and the lamp life are important. For example, an LED lamp life might reach 60.000 hours while an HPS only reaches 20.000 hours, but HPS might reach higher luminous efficacy (Boyce 2014).

The study and choice of the optimal lighting levels for pedestrian needs after-dark can also improve the economic and environmental impact of energetic use in public lighting. The costs of road lighting are quite high to local authorities. Using open data regarding the kWh consumption of street lighting of the period between 2015 and 2016 from York, a city in the UK and the non-household value of electricity in the UK conveyed in the final report of the European Commission study on energy prices, it was estimated that the cost of streetlights was of 308,886€, around £278,277. This is the value estimated for streetlights for an area of 34 km^2; if a similar estimation is used for the greater metropolitan area of London (1737.9 km^2) an estimated cost of £14,224,047 can be calculated.

The UK Road Investment Strategy commencing in 2015/2016 running until 2019/2020, set eight areas of focus: (1) improving the safety of the road network, (2) enhancing user satisfaction, (3) promoting the smooth flow of traffic, (4) promoting economic growth, (5) producing better environmental outcomes, (6) supporting vulnerable road users such as cyclists and pedestrians, (7) achieving efficiency and (8) keeping the network in good condition (Department for Transport 2015). In order to support cyclists and walkers and promote active travel an estimated of £100 million was allocated. Operational decisions were made with regards to the lighting of the road network, namely by turning off lighting in some areas to reduce gas emissions and consequently lowering the environmental impact of lighting. Another change introduced, that aimed at carbon print reduction was the shift to LED light sources. This strategic planning shows a greater will to invest in energy-efficient technology, but then again, the manner that this intervention will encourage active travel and promote road safety is vague.

1.2.2. Photometrics

Photometric quantities are accounted for in lighting design and installation. These are various, but for this research, Illuminance is the most pertinent. As verified in Table 1, the average horizontal illuminance ($\bar{E}$) ranges in the BS EN 13201-2:2015 from 2.0 to 15 lux and the minimum horizontal illuminance (E_{min}) from 0.4 to 3.0 lux respectively. Horizontal illuminance is the metric mostly referred to in research and standards for pedestrian lighting design. It is measured at ground level and average and minimum values are considered and used as reference for the whole surface (CIE 115-2010).

The P-lighting classes also set minimum Semi-cylindrical ($E_{sc,min}$) and minimum vertical ($E_{v,min}$) illuminances to ensure facial recognition and thus, interpersonal judgements (BS EN 13201-2:2015). Semi-cylindrical illuminance refers to the luminous flux falling on a curved surface of a semi-cylinder. Hence, its measurement is done at a 1.5 meter height above the ground-oriented towards the main directions of pedestrian movement (BS EN 13201-3:2015). Similarly, vertical illuminance varies with the direction of interest and is measured in the same manner. Hemispherical illuminance is the light that falls on a hemispherical surface that is horizontally parallel in its base to the ground level.

Averaged illuminances refer to the arithmetic mean of 10 measurement points in the longitudinal direction between luminaires (BS EN 13201-3:2015), except when the distance between luminaires is higher than 30 meters. Then, the distance between measurement points should be a maximum of 3 meters, which is likely to provide more measurement points. From these measurement points, minimum and maximum illuminance values can be identified, which are crucial to calculating uniformity.

Uniformity is the lighting level that demonstrates the spatial distribution of illuminance. In BS EN 13201-3:2015 overall uniformity is the ratio of the minimum illuminance value measured at any point to the average (E_{min}:$\bar{E}$). The same British Standard defines that longitudinal uniformity is to be calculated as the ratio of the minimum illuminance to the maximum illuminance registered in the measurement grid (E_{min}:E_{max}). Some American studies choose to look at longitudinal uniformity rather than overall uniformity (Narendran, Freyssinier & Zhu 2016; Nasar & Bokharaei 2017; Bullough, Snyder & Kiefer 2019).

1.3. What does a pedestrian need when walking?

Good lighting allows pedestrians to detect obstacles in the pavement, perform interpersonal judgements and feel safe. Although the focus of the present research is the latter, detecting obstacles and performing interpersonal judgements are also pedestrian critical visual tasks. Thus, these are briefly addressed in sections 1.3.1. and 1.3.2. in order to provide a wider perspective on the illuminance levels adopted, allowing a deeper understanding of the state-of-the-art of standards and research on-road lighting. This is important because road lighting for pedestrians is a common lens applied to fulfil different pedestrian needs.

1.3.1. Obstacle detection

Examining the pathway for potential obstacles is a critical visual task for pedestrians (Fotios & Cheal 2013). Detecting obstacles or poorly cared for pavement is important because pedestrians might trip and fall resulting in injuries. The elder population are more vulnerable to road hazards due to more deteriorated vision and agility conditions. Thus, the lighting for obstacle detection studies enables the understanding of the necessary levels to avoid physical injuries in pedestrians.

Fotios and Cheal (2010) have analysed peripheral detection of obstacles, in a laboratory setting using three illuminances (0.2 lux, 2 lux and 20 lux). The findings suggested that higher illuminance improved obstacle detection. This study also looked at the relationship between the S/P ratio and obstacle detection, but results showed that it was only relevant at the lowest illuminance level. A study was conducted to investigate these results further (Uttley, Fotios & Cheal 2017). While the previous study used a static obstacle, this study used a dynamic fixation task and participants walked on a treadmill while performing the visual tasks. This enabled a simulation of the real environment complexities. Walking down a road requires motor coordination and sensory information assessments of the environment, such as potential hazard identification. Results confirmed that the S/P ratio only impacts higher visual performance at the lowest illuminance and that the higher illuminances reach a plateau of detection probability at approximately 2.0 lux (Uttley, Fotios & Cheal 2017).

Eye-tracking data seems to suggest that detection is made at an approximate distance of 3.4 meters (Uttley, 2015). Fotios and Uttley (2018) found that the horizontal illuminance level that allowed pedestrians to detect a 10mm obstacle at a 3.4m distance ranges from 0.22 lux up to 0.93 lux. This range is dependent on the pedestrian age and the S/P ratio. This agrees with previous research that concluded that the S/P ratio had an effect at 0.2 lux.

The main contributing factors for obstacle detection are the detection distance and the luminaire position with regards to the obstacle. Fotios et al (2020) investigated the implications of object height for its detection, finding no relevant relationship. However, their findings suggest that the spatial arrangement of luminaires has a significant effect on detection probability. Three lamp positions were used (behind, overhead and in front), showing that detection is lower when the luminaire is in front of the participant. This might be because of lighting glare or because the light positions did not provide a uniform spatial lighting distribution.

1.3.2. Interpersonal judgements

The development of eye-tracking technology allowed the empirical study of the relevance of interpersonal judgements. Whilst the path and other people have been evidenced as the visual attentional focus of pedestrians (Fotios, Uttley & Hara 2013), in a study on visual fixations of pedestrians outdoors it was found that when analysing the fixations on other pedestrians considering the actual number of people that the test participants encountered during the experiment, there is a 86% probability of fixating on other pedestrians (Fotios, Uttley & Yang 2015). This evidences the importance of being able to assess others when walking.

In a recent study, that looked at 5955 visual fixations on other pedestrians, derived from 54 eye-tracking videos (21 recorded in daytime and 33 after-dark), results show that individuals tend to evaluate other pedestrians at 14 meters mean distance (Fotios, Uttley & Yang 2015). However, how participants evaluated people walking individually or in a group differed. Groups are evaluated at a greater distance than individuals. This might be because individuals take longer to judge a group's intentions or behaviour and might feel more intimidated by groups than just one pedestrian. Fotios, Uttley and Yang (2015) results also showed that the evaluation distance decreased after dark, which is likely to relate to the light level artificially available, suggesting that the illuminance levels are relevant for the distance at which people are able to perform interpersonal judgements.

Ailin et al (2019) conducted a study after-dark to understand the optimum illuminance to discern facial expression at 4 meters. This study was carried out in a residential environment with 12 LED sets with 13 participants, that scored a number of factors such as sharpness of face. Their findings suggest different levels than the currently proposed in the BS EN 13201-2:2015 (Table 1). For an average horizontal illuminance of 10 lux, a vertical minimum of 1.4 lux seems to be enough for satisfactory facial recognition (Ailin et al. 2019). This is a significant difference from the 3 lux of minimum vertical illuminance indicated in BS EN 13201-2:2015. Thus, it is important to consider other pedestrian needs to understand whether the current standards could be further optimised.

1.3.3. Safety

Road lighting has been pointed out as a crime deterrence tool and as a means of reassuring both residents and pedestrians. In a study that used surveys before and after a change of lighting in an area to verify feelings of reassurance of pedestrians outdoors, respondents reported feeling more confident following that alteration (Davidson & Goodey 1991). Reassurance is defined in this thesis as the confidence a pedestrian has when walking after dark (Fotios, Unwin & Farral 2015) (section 2.2). In the last few decades, research has examined the lighting-safety relationship showing that road lighting might have an effect on feelings of reassurance (Herbert & Davidson, 1995; Boyce et al. 2000) and the crime itself (Painter 1996; Pease 1999). Crime prevention guidance and studies have also pointed out lighting as means to increase safety in an urban environment (Newman 1975; Deryol & Payne 2017; Piroozfar et al. 2019). A possible limitation of these studies is that lighting was provided as an option in the surveys (Fotios, Unwin & Farral 2015). To investigate further the reasons for reassurance after-dark among pedestrians, Fotios and Unwin (2013) conducted a three-stage interview, considering photographs taken by participants of areas that they considered unsafe. The participants were asked to explain the reasons behind not feeling safe in these places. Lighting (87%) or the lack of appropriate lighting (85%) was frequently mentioned.

Also, Fotios and Castleton (2016) analysed the results from six studies with regards to pedestrian reassurance and road lighting, confirming that the common conclusion is that higher illuminance provides higher safety feelings. However, the authors highlight the lack of technical rigour concerning research methodology. Some studies do not report the lighting levels or statistical significance of results.

On the other hand, other studies investigated what precise level of illuminance is enough to make people feel reassured (Boyce et al. 2000; Knight 2010). In a study in parking lots, a horizontal mean illuminance of 20 to 30 lux was indicated as the plateau to which no further increase in perceived safety would be experienced (Boyce et al. 2000).

Recent studies in car parks have confirmed that perceptions of safety do not seem to have a significant increase after 10 lux of horizontal mean illuminance (Narendran, Freyssinier & Zhu 2016; Bullough, Snyder & Kiefer 2019; Bhagavathula & Gibbons 2020).

There are other metrics that seem to have relevance for pedestrian safety such as spatial distribution of lighting (Narendran, Freyssinier & Zhu 2016; Nasar & Bokharaei 2017; Bullough, Snyder & Kiefer 2019), and the S/P ratio (Knight 2010).

1.4. Thesis structure and aim

The present thesis aims at confirming if there is a verifiable effect of road lighting over the reassurance of pedestrians when walking after dark. If so, which are the optimal lighting levels and metrics to be used for this purpose. Moreover, the effect of alleged limitations of previous studies is investigated.

This was done through two field studies, using surveys to collect assessments on reassurance and at times lighting on several locations. The resulting data was explored and analysed to answer the following questions:

- Is Boyce et al (2000) day-dark approach better than just evaluating after-dark scenes?
- Are single items enough in portraying the fear of crime-reassurance feelings?
- Which lighting metrics reassure pedestrians?
- What is the optimum level of those metrics?
- Is there a quantifiable impact of imagination or re-called after-dark scenarios that might have affected previous results?
- Does asking about perceived brightness provide a similar result to analysing measurable lighting metrics?

To achieve this aim, the thesis is divided into three parts:

- Part one is a literature review comprised of the current chapter (Chapter 1), Chapter 2 and 3. Chapter 1 provides an overview of the lighting standards and technical definitions needed for the study of road lighting. Chapter 2 looks at the way individuals experience the urban environment, drawing from the early work of Canter (1977) and Appleton (1975) and establishing links to road lighting research. Section 2.2. of the same chapter identifies the predictive and contributing factors to fear of crime, as described in previous research, determining the relevance of the study of fear of crime, perception of safety and reassurance. Chapter 3 scrutinizes the methodological limitations and challenges in the study of road lighting for reassurance through the identification of issues in the method typically used for measuring fear of crime (section 3.1.) and concerning the approach and accuracy in the study of the effect of road lighting in perceived safety (section 3.2.). Together, these chapters outline the state of the art of the research of road lighting for enhanced safety perceptions, providing the theoretical framework for the practical approach to the aim of this thesis and defining a set of research objectives (section 3.3.).

- Part two reports two exploratory field studies focused on pedestrian perceptions of safety and the role of road lighting on these. Chapter 4 details a first field study that investigates the relationship between different illuminances and reassurance evaluations. Chapter 5 reports a second study that aims at confirming the previous study results. Chapter 6 examines the implications of focusing on subjective assessments of lighting, perceptions and imagined darkness in the study of lighting. Result discussion is provided at the end of each chapter.
- Part three provides a conclusion to this thesis, providing a reflection on limitations and notes for further research (Chapter 7).

1.5. Summary

Artificial lighting potentiates the routine activities of individuals past daylight times. However, its installation, usage and maintenance have economic, environmental, and social impacts. This evidences the need for road lighting network optimisation in terms of energy efficiency and evidence-based design. Chapter 1 presented the current lighting standards in the UK and provided a reflection on the pedestrian needs to be addressed by road lighting design.

Appropriate road lighting for pedestrians should address their need to:

- prevent physical injury by detecting obstacles on the pathway,
- feel reassured with regards to their personal safety,
- assess other people at a sufficient distance to respond as necessary,
- see and be seen by other users, such as drivers and cyclists.

Instead, the criteria address travel speed, traffic composition, parked vehicles, the existence of other ambient light sources, facial recognition needs, and the influx intensity of users to the road by attributing a rating with no further guidance. Obstacle detection, interpersonal judgements and personal safety are likely to need different illuminance thresholds, as do the needs of other users, such as drivers and cyclists. However, it seems to remain unclear the adequate levels for pedestrian reassurance. The present thesis aims to examine the optimal levels of lighting through diverse photometrics as described in chapter 1. Furthermore, Chapter 2 and 3 will discuss the methodological implications of the study of perceptions of the environment, and namely road lighting as its component, and fear of crime and reassurance. These chapters raise questions and serve as the basis for the research produced for this thesis.

Chapter 2. Experiencing the built environment

The experience of the built environment is complex, due to the many layers to the urban tissue and the individual perception of each person. This chapter focuses on two theoretical constructs on how the urban context is perceived by individuals linking it to lighting and fear of crime research. A construct is to be understood as a set of underlying ideas based on distinct pieces of evidence that together constitute an overall concept, dimension, or theory.

The Oxford Dictionary of English (OED 2015) defines fear as "*an unpleasant emotion caused by the threat of danger, pain, or harm*", "*a feeling of anxiety concerning the outcome of something or the safety of someone*" and "*the likelihood of something unwelcome happening*". From the perspective of Psychology, fear is a primary emotion (Ortony, Clore & Collins 1988), that serves the purpose of survival (Maslow 1943). If fear is about survival, it can be assumed that the perception of potential victimisation in a certain context can activate a fear-based response, such as avoiding certain activities. Thus, it is important to examine the process behind the perception and interpretation of a certain space.

Road lighting, crime and fear of crime have been studied and constantly associated. This is because road lighting fundamental aim is to allow visibility after-dark, artificially replacing daylight (Davidson & Goode 1991). The users' safety is the highest benefit of a visible environment. This safety can translate into a feeling of reassurance (Fotios, Unwin & Farral 2015) and increased time to recognise a hazard and respond accordingly, as obstacles (Fotios et al. 2020) or other users' intentions (Ainlin et al. 2019). Thus, a higher safety perception promotes physical activities after-dark (Foster et al. 2014), the use of public transport (Department for Transport 2015), social recreational activities (Bolger & Bolger 2019), and even, a sense of territoriality, cohesion and sense of being cared for in residents (Boateng 2019; Valente, Pertegas & Olmos 2019). Considering these implications, road lighting has been studied and said to assist in decreasing fear of crime and crime itself and in encouraging the movement of people throughout the urban tissue.

Box, Hale and Andrews (1988) have pointed out that fear of crime disrupts community cohesion because it leads to distrust in the neighbours and the environment and it creates a collective perception that certain public areas are not safe. This might encourage residents to look for safer areas, leaving behind only the individuals with no economic possibility to move out. Thus, the safer movement of people could even have an economic influence on the marketplace pricing of residences.

Fear of crime and previous victimisation have been associated with a reduction in general quality of life (Hanslmaier 2013). This is due to the psychological and physical effects caused by these feelings and perceptions. This phenomenon has been linked with higher depression scores (Ruhs, Greve & Kappes 2017) and social disengagement (Yuan & McNeeley 2016; Piscitelli & Perrella 2017), and to interfere with general health (Jackson & Stafford 2009; Lorenc et al. 2013; Macassa et al. 2017). Stafford et al (2007) in a longitudinal study that used data collected from 2002 to 2004 from more than 10.000 individuals based in London have concluded that there is a correlation between a greater level of fear of crime and the decreasing of health-promoting physical and social activities. Foster et al (2013; 2014), in a longitudinal study, have also found evidence that fear of crime discourages weekly walking activities in an average of 22 minutes. Therefore, this phenomenon might be of consequence to public health.

A recent study conducted in New Zealand aimed at understanding the relationship between parents' perceptions of their neighbourhood and children's use of it in terms of active travel (Lin et al. 2017). This study detected that children could engage more in independent walking and cycling activities when the parents interpreted the neighbourhood as cohesive. This is relevant as it might have developmental costs to children, as their physical, social and cognitive development is impacted by their autonomy to explore and engage with the outside world (McIlveen & Gross 2002).

Fear of crime has been argued in its nature (Gabriel & Greve 2003; Gray, Jackson & Farrall 2010; Chon & Wilson 2016), measurement (Hinkle 2015; Collins 2016; Alfaro-Beracoechea et al. 2018) and true value for policies (Klama & Egan 2011; Singer et al. 2019), and consensus in research was not always reached. This could be critical as governments, funding bodies and numerous industries have been drawing from a sometimes-antithetical body of research, thus with an imprecise concept, impact and representation in society (Lee 2001).

This chapter attempts at understanding the aspects in the built environment that might promote fear of crime and the contribution of road lighting to increase safety in the urban space. Section 2.1 focuses on the psychology of place and prospect-refuge theoretical constructs, while section 2.2 provides a conceptualisation of fear of crime and insight on the predictive aspects to it.

2.1. Introduction to the experience of road lighting as part of an environment

Although several studies looked at the empirical relationship between road lighting and crime and fear of crime, results are disputed. Several reasons might explain this:

(1) Lighting is a highly technical subject of study, as described in chapter 1. Meaning that objectively studying lighting requires specific knowledge on international standards, lighting source, chromaticity, photometrics and others. Some studies are oblivious to these details.

(2) The wider studied impact of lighting is one of social nature (e.g. as a crime-prevention tool), so a panoply of individual and cultural characteristics influences results.

(3) Lighting is a single component of a broader complex urbanistic landscape. Thus, other urban elements also contribute to a safety perception in each built environment.

Several theoretical constructs support the use of lighting as a supportive environmental component for pedestrian and resident reassurance or crime prevention (Appleton 1975; Newman 1975; Canter 1977). In the following sections, the Psychology of place (Canter 1977) and Prospect-Refuge (Appleton 1975) constructs will be discussed in detail considering posterior lighting studies undertaken. These are relevant to scrutinise the role and study of lighting in the built environment.

2.1.1. The Psychology of place

David Canter's work "The psychology of place" published in 1977 was a pioneer in attempting an understanding of the cognitive processes behind the internal representation and consequent interpretation of places. Cognition is a wide concept that encompasses both the knowledge gained by sensorial experience and the perception derived. Perception in itself refers to the awareness and response to the stimuli. Thus, perception refers to the internalisation of the captured and processed sensorial information (Ruhs, Greve & Kappes 2017). Considering this, Canter (1977) tried to grasp which cognitive systems are relevant in the experience, internalisation, and assessment of the surroundings. The complexity of cognition and the individuality of the psyche still generate relevance for research. Understanding how the built context impacts individuals and finding the communalities is fundamental to inform urban planning, policing-oriented practices, among others.

Environments emit an infinitude and variety of constant stimuli which entirety is impossible to process by individuals (Canter 1977). Thus, this information is not always on conscious focus, frequently being secondary and collected at a subconscious level. For example, a single residential road at night might bring forth information regarding visibility and artificial lighting, litter, residents, pass-byers, sound, the presence of animals, among others. This idea highlights one relevant limitation to the study of lighting. Road lighting is just an integral part of a context. The issue is then to ensure that the observed effects are resultant from lighting and not from other landscape components.

Boyce et al (2000) proposed and applied a day-dark approach to understanding the effect of lighting on perceived safety in parking lots. The day-dark approach is based on the principle that (1) lighting only makes visible what is in an environment to be seen and (2) an individual can only feel in that environment as safe as during daytime. Thus, resorting to a repeated measures design, participants visited a series of parking lots with different illuminance levels and answered a questionnaire on their safety feelings during daytime and after-dark (Boyce et al. 2000). By comparing the difference between daytime and after-dark ratings, it was possible to establish the disparity between the reassurance felt in each condition. This is shown by the relevance of correlations of the goodness of the lighting ($R^2 = 0.82$) and the brightness of the lighting ($R^2 = 0.83$) with day-dark differences of safety appraisals. If road lighting can only contribute to improving the night-time natural safety circumstances to resemble the daytime condition, by considering the difference between daytime and after-dark ratings one should be excluding the other elements in the landscape. This approach is based on the assumption that the fundamental difference, in the same environment, between daytime and night-time is road lighting, which only makes visible what is there to be seen. This approach is further commented with regards to methodological limitations of only studying after-dark ratings of the lit environment (section 3.2. and 3.3.).

Canter (1977) also argues that the personal conceptualisation of spaces stems from a recognition of symbolism in a context. This symbolism leads to recalling and associating that perceived information with previous experiences and the resultant internalised representations. This capacity to activate the memory of experience allows human beings to read and interpret unknown surroundings, and whenever needed, draw upon, for example, for survival or protection. As closer examined in section 2.2., fear of crime is an example of a phenomenon that originates in a representation and interpretation of risk and self-efficacy in a certain situation (Bandura 1997; Ruhs, Greve & Kappes 2017). The studied impact of the previous victimisation in fear of crime is an illustrative example. People targeted for a crime in the past have been proven to report to be more fearful of crime (Boateng 2019). Thus, the presence of certain elements in an urban scene that was present before, such as an empty or with dimmed lighting road, could trigger anxiety because it remembers the pedestrian of a past experience in a similar context.

The contextual symbolic trigger is dependant on the personal experiences of reality. These might range from visibility to the presence of people in the street. It is important to emphasize that this internal model is dynamic and continuously evolving. Considering this, it is also possible through urban design, for example, the adequate application of road lighting, to establish healthier spatial images and more reassuring places. Contextual symbolism triggers not only the recall, association, and interpretation of the environmental information but also prompts a reaction to it. This reaction can be expressed in intentional behaviour, such as choosing a route to walk home, or in unintentional behaviour, such as physiological responses (Gabriel & Greve 2003). Castro-Toledo et al (2017) attempted at measuring the real-time manifestation of fear of crime in a controlled lighting environment. The results supported that it is unlikely to be the decrease in lighting levels that cause this reaction, but rather the individual interpretation of the reduced visibility as an element of the social fabric. In this perspective, Green et al (2015) also suggest that it is the interpretation of the social fabric according to an assessment of the quality of lighting that prompt certain perception. For example, the registered anxieties are suggested to be rooted in the analysis of investment of the government and neighbours in those areas. An adequately lit area might be interpreted as an area that is maintained and cared for by the residents and the government. In a simplistic economic model, monetary investment is done when there is worth to something leading to potential gains. Assuming Canter's premise, it can then generate an interpretation that the area is safe because it is invested in. Depending on the personal internalised model, an individual might infer the social status, economic growth or police investment in that area.

From this perspective, the individuality of the process of conceptualisation of place, due to intrinsic subjectivity, makes generalisation complex. Using sketches in his studies, Canter (1977) explored the personal cognitive systems and subsequent distortion of reality accordingly to the previously explained internal model. In these studies, the complexity of detail, the emphasis on certain elements and the perceived spatial link between points is said to demonstrate these particularities. Canter (1977) suggests that these sketches and the description of places portray the actions and reactions that occur with regards to an environment. This is to say that this method allowed the researchers to identify the roles undertaken and how an individual feels about a place. The principle of distortion adverts to the complexity generalisation because the spatial assessment is always dependant on prior experience and posterior expectation based on the elements present in each scenario.

Cognitive systems are formed in the extended and recurring interaction with the environment. These interactions occur during ongoing activities, for example in between getting out of the house and reaching the workplace. These environmental interactions influence our spatial awareness and representations. Consequently, places are conceptualised with a personal approach with regards to their purpose, use and other elements of the urban tissue.

The relevance of individual differences for spatial interpretation and representation is illustrated in a study, with same-aged children, living in the same neighbourhood, that were asked to sketch this neighbourhood (Florence Ladd 1970, cited in Canter 1977, p.12). Results revealed clear distinctions regarding geographical extension, detail, the importance of places in the neighbourhood, showing that the house had greater importance. This pointed out that individuals’ spatial representation emerges, then, from cognitive processes, interactions, and attributed significance.

This conceptualisation of space, which considers actions and derived reactions, that constitute a dynamic internal model, points out the need to address psychological perceptions and triggers of places and resulting influence in behaviour (Canter 1977). Hence, the cognitive systems, bring forth an emotional response that determines the behaviour. Space and this perceptive conceptualisation might determine the behaviour of individuals. This paradigm is present in many posterior studies that tried to address communalities in the response to the environmental design (Nasar & Fisher 1993; Blobaum & Hunecke 2005; Andrews & Gatersleben 2010).

In the design of places, Canter (1977) considers it of crucial significance to study not only the reality but also the perceived reality. A place is not circumscribed to its physical components, but it also incorporates social implications and applications, in a societal and personal system. This personal system in each place reflects the perceived environmental role rooted in social differentiators, such as gender, job, modes of travel, among others. In this manner, Canter (1977) suggests that emotion directs preference and consequentially behavioural choices. Understanding the environment and the movement of people requires a study of real and perceived physical and contextual cues that influence preference. This allows an understanding that brings clarity to socio-economic, political, and technological design, policy, planning and investment in locations.

2.1.2. Prospect-Refuge

In “The experience of landscape” published in 1975, Jay Appleton presented a theory named Prospect-Refuge that contemplated the survival of human instincts and needs influencing the aesthetical readings of a certain environment. Landscape architecture is concerned with the design of the human experience in the outdoors (Appleton 1975). Thus, also concerned with the study of the design of urban landscape for a more reassuring experience.

Appleton (1975) defines landscape as a complex tissue that comprises not only the evident urbanistic-designed traits but also socio-economic aspirations. Thus, understanding the motivation behind rejection or acceptance of a certain landscape is a central question.

The manmade landscape is directed by its functionality to human life. However, functionality will only be fully accomplished if the interpretation of the aesthetic is considered. It is this interpretation of environmental cues that are individual and that creates difficulties in terms of research. According to Appleton (1975), we are only capable of observing an inferred perception, through recorded symptoms or an explanation of a reaction to a stimulus. The landscape is said to lower the users’ anxiety through displaying protective tools or places to find shelter, so it is important to understand empirically which urban elements impact individuals.

In a reassurance study, participants were asked to photograph streets that made them feel reassured and uneasy after-dark (Fotios & Unwin 2013). These participants were then asked to point out the reasons to have chosen those streets. The analysis of 53 interview transcripts showed that the presence or lack of lighting and access to help were the main relevant features of a safety assessment. Thus, the relevance of the landscape is not the actual potential of the environment but the perceived potential through its displayed elements. These can be, for example, shapes, light and shadow patterns, and spatial arrangements. In summary, the interpretation of the aesthetic informs its functionality in terms of the primal needs of safety. Furthermore, if the urban aesthetic informs on the functionality and potential of a space, it will also direct the behaviour and movement of people in space.

This is the key premise to the Prospect-Refuge Theory proposed by Appleton (1975). The author establishes two key features to the experience of the environment: prospect and refuge. Focusing on an example related to the topic of this thesis, while walking at night, a pedestrian might consciously or unconsciously look for escape routes or adopt protective behaviours such as choosing well-lit streets. In the case of the crime itself, the design of the environment might attract potential offenders, motivated to specific criminal opportunities. For example, a low-lit park might create adequate opportunities for theft to occur if opened at night, due to low prospect and isolation. McCormick and Holland (2015) have studied the implementation of crime prevention tools in recreational settings in 129 cities from the United States of America. Although most cities reported lighting in their parks, 64% of the local authorities reported keeping the lights off in the parks after-dark to discourage its use. This is an interesting use of lighting as research focuses on the optimal use of lighting to enable visibility. However, in this case, lighting is used assuming that if there is no visibility at all both potential victims and offenders will be discouraged. This can be done because parks are recreational spaces and not essential road network arteries. Although it is not a valid application for residential roads, it evidences the power of adequate, inadequate, and inexistent road lighting in determining the use of space.

Prospect is defined as the capacity to see unobstructed and Refuge is the spatial opportunity for protective shelter. Therefore, this theory is rooted in the duality of visibility: to see and not be seen. The analysis of landscape has then to be done considering how the urban design encourages or facilitates viewing between observed and observer (Prospect), and how the individual might escape or find shelter (Refuge). Appleton (1975) suggests that there are direct and indirect prospects that can benefit from primary or secondary vantage points. For example, lighting would be an indirect prospect, as it is essentially symbolic for a greater quality of the vision field. Refuge can be found, as described by the author, in numerous elements that are classified by function, origin, substance, accessibility and efficacy. Although, the hazards to a prospect can be numerous (e.g. vegetation, fog, narrow alleys, crowds), some of these can also offer refuge. It is important to bear in mind that the landscape is a merge of prospect and refuge symbolisms interpreted differently depending on the individual (Smith & Samuelson 1997). According to Appleton (1975), the evaluation of these components depends on (1) the presence of prospect-refuge objects, (2) the manner and intensity of this representation, (3) the spatial arrangement, (4) the balance of the prospect and refuge symbols and (5) the physical media of communication of all of this to the observer.

The importance of this theoretical framework for the study of lighting and fear of crime seems evident. The criminal behaviour depicts primal hunting behaviour, where the motivated offender is a hunter and the common citizen a prey. Then, road lighting appears as a complement to other prospect and refuge aspects as well as a prospect element on its own. Lighting after-dark enhances shapes and creates shadow. Thus, this element allows the visibility of the imagery, so it is fundamental to all prospects. Furthermore, light allows shadow, which has a functional role in concealment. The inside darkness of refuges is associated with safety. Due to the limitless combination of intensity, diffusion and shadow that lighting arrangements might create it is a rather complex object of study.

This theoretical framework served as the reference for the study of the impact of road lighting as a landscape feature. Nasar and Fisher (1993) studied three environmental features (prospect, concealment, and boundedness) in hotspots and their influence on fear of crime and spatial behaviour. Boundedness refers to an urban design that presents blocked or closed areas, such as enclosed footpaths, while concealment refers to structural aspects that allowed successfully perceived hiding. The study was carried out on the campus of the Ohio state university, in three different areas, and it considered *in loco* answers from a total of 258 individuals. One area presented significantly higher contrast in concealment spaces and prospect. The study asked participants to report their feelings when walking that area both during the day and night in an open-ended question. Participants were asked to explain their reasons for possible fears and how these induced changes in behaviour. Also, eight spots of the campus were presented to the participants and respondents were asked to report their feeling of safety.

Results showed that both fear and crime increased in the areas that presented high concealment and low prospect. Thus, suggesting that a consideration of this in spatial design might enhance safety. The reasons behind fear pointed out by the respondents were physical and non-physical. However, it is important to mention that the area that displayed higher prospect-refuge feature contrast, also produced more environmental designed motivations. These physical features were concealment spots, blocked escapes, and inadequate prospect, usually related to inadequate lighting. The participants mainly cited concealment (49%), followed by lighting (33%). From the self-reported fear, due to these aspects, avoidance and protective behaviours and collective actions were adopted (Nasar & Fisher 1993). The direct observation of pedestrian behaviour was also applied to allow to note that the behavioural observations supported these results. Pedestrians tended to avoid areas with a low prospect, high concealment and blocked escape after-dark.

Boomsma and Steg (2014) inferred further into these features’ relationship with lighting and its impact on perceived safety. This study was carried out in a lab, using four virtual environments, displayed for 40 seconds. The 88 participants were asked to imagine themselves walking these environments and after each scene, they would rate it in terms of perceived safety and acceptability of lighting level. It is important to mention that these four scenes were created and manipulated to exhibit two different entrapment and two different lighting conditions. Results indicated that low lighting levels were evaluated as less acceptable, as it led to lower social safety perception. However, when the perceived safety increased, the acceptability of the urban conditions did as well. Thus, the importance of entrapment conditions was, as expected considering the theoretical framework from Appleton (1975), mediated by the visibility. This means that the scene was perceived as more threatening, when there was high entrapment and low prospect, leading to low acceptability of that presented urban environment.

More recently, van Rijswijk and Haans (2018) explored this hypothesis that lighting might serve as a safety cue on itself. To understand the relevance of it in comparison to the prospect-refuge cues in predicting safety evaluations of the environment, two studies were undertaken. Both used a set of six images displaying night-time settings with different environmental characteristics. In a lab setting, participants were exposed to the picture for 5s and then asked to fill a survey. The first study focused on perceived safety and the spatial attributes (prospect, concealment and entrapment), whilst the second study gathered perceptions on the quality of lighting of the same images. Results from the first study corroborated Appleton’s premise (1975) that the balance and integration of these are relevant for the interpretation of the landscape, confirming that assessments of prospect, concealment and entrapment are associated with perceived safety in an environment. Safety ratings were positively correlated with the prospect and negatively correlated with concealment and entrapment. It is important to mention ratings for urbanistic features and perceived safety were collected independently.

In the second study (van Rijswijk & Haans 2018) the relationship of perceived lighting quality and previously collected safety evaluations were examined. The objective was to understand if variations in prospect, concealment, and entrapment assisted lighting quality appraisals. Results demonstrated that this perceived quality of lighting offered low predictive power beyond the one from actual urbanistic characteristics. This means that this lighting perceived quality followed the same trend as described in study one, correlating positively with safety assessments and prospect and negatively with entrapment and concealment. It is important to refer to Appleton’s considerations on lighting in this pattern. Lighting is a complement-form of prospect, as it allows to see and be seen, and illuminates the symbolic imagery of the landscape. In this perspective, these results are corroborative of the role of lighting in safety perceptions.

2.2. Experiencing fear of crime

The conceptualization of fear of crime has been widely examined. However, the conceptual basis of these investigations diverged. Many researchers read fear of crime as the perceived likelihood of victimisation (Killias 1990) whilst others considered it the emotional response to the potential victimisation (Farrall, Gray & Jackson 2007). This shift in focus is said to inflict a result variance (Bolger & Bolger 2019; Hinkle 2005), thus providing a panoply of findings that at times seem not to clarify but only add up to the nebulous definition of fear of crime.

In the early years of the fear of crime studies, Garofalo (1981) outlined fear of crime as an emotional reaction that depends on a sense of danger and subsequent anxiety, which is produced by the perceived opportunity for physical harm to occur rooted in an individual interpretation of environmental cues. The author, then, differentiates between fear, which related to physical harm, and worry, which is said to link to property crime. Three principles ought to be examined in this definition.

Firstly, it is important to make a historical consideration. Since the publication of Garofalo's (1981) research, the importance of property and its role in everyday life has shifted. Technology has strongly developed, and it has increasingly centralised financial, professional or even emotional resources. For example, a mobile phone might give access to confidential information that might be personal, corporative, or even governmental. Considering this change in the power and importance of property for an individual in the twenty-first century, this assumption that personal and property crime develop necessarily different emotional states is unlikely.

Then, the personal interpretation of cues seems to be a crucial contributor element for fear of crime. This interpretation is resultant from an individual evaluation of a particular situation that is a by-product of personality, socio-economic context and life experience (Ferraro 1995). For example, certain individuals will read the presence of beggars as a cue of the disorder leading to the possibility of a more serious offence, while others might find that presence unthreatening (Jackson 2005). Farral, Gray and Jackson (2007) state that fear of crime is a side effect not of the surroundings but rather of this subjective analysis of these surroundings and if there is a social formal or informal effective control in place, which can provide a sense of safety. This instinctive screening and evaluation of an environment is the basis for a cognitive appraisal, also named perception (section 2.1.).

Fear of crime exists simultaneously on an emotional and cognitive plane, yet only a few studies carried out considered both the perception of risk and the derived emotional state. Hinkle (2015) acknowledged that out of thirty-five studies on this topic, only fourteen included a measure of the emotional dimension. This is relevant because measuring the perception of risk in a given situation is different to measuring the feelings of safety, emotional responses such as anxiety and worry, or behavioural reactions such as avoiding a certain location.

Some recent studies seem to generally agree that the *supra* mentioned constructs are all integrant parts of the wider phenomenon named 'fear of crime' (Gabriel & Greve 2003; Mesch 2000; Rader 2004; Rader, May & Goodrum 2007; Rader 2017). Fear of crime is then assumed as a multifaceted phenomenon that starts with a perception, which prompts an emotional state and consequential behaviour. Thus, fear of crime is a weighting of the potential risk of being victimised considering one's vulnerability and the context, which results in a particular emotional state (e.g. anxiety, worry, panic) that leads to the adoption of a set of constraining or avoidance behaviours. For example, an individual might perceive that the neighbourhood is prone to criminality after-dark, which results in some anxiety or worry, thus this individual avoids going out after dark. Rader, May and Goodrum (2007) examined this reconceptualization, establishing this dimensionality of fear of crime. It was also found that fear of crime might be both an effect and a cause for further development of this phenomenon. This study was also able to determine at least nineteen avoidance behaviours, being the most common ones avoiding exercising at night (33%), shopping (9%) and leaving the house unattended (8.8%), and a series of defensive behaviours, such as installing outdoor security lights (38.5%) and door bolts (35.7%). This reconceptualization of fear of crime as multidimensional is critical when considering research methods (section 3.1.).

The present thesis adopted the concept of *Reassurance*, rather than *Fear of crime*. As abovementioned, the phrasing has a crucial influence on the manner perceptions are reported (section 3.2.). Thus, the use of fear of crime phrasing on itself might be suggestive and inducing of the emotional states or at least of their reporting. As the present research is carried out in a real environment such consideration is of particular importance.

The use of this conceptualisation rather than fear of crime *per se*, should not influence results as it is understood that it is the opposing facet on the spectrum. Fotios, Unwin and Farral (2015) described reassurance as the confidence that an individual has when walking alone at night. Therefore, this term refers to the sense of safety or risk perceived, felt and behaviourally manifested.

2.2.1 Predictive and contributing factors

There is a multitude of characteristics that are said to be predictive of fear of crime, such as age, gender, ethnicity, education, economic status or previous victimisation. Each of these aspects has a potential for heightened vulnerability.

Killias (1990) defined a model of vulnerability, drawing from the *Self-efficacy Theory* (Bandura 1997) that admits three dimensions: (1) exposure to risk, (2) seriousness of consequences, and (3) loss of control. The higher the vulnerability perception or feelings, the higher the fear of crime is in an individual (Adams & Serpe 2000; Rader, Cossman & Porter 2012; Valente, Pertegas & Olmos 2019).

Efficacy is defined by Bandura (1997, p.36) as a set of subskills an individual has that is operationalised in different levels to respond to certain scenarios. This is affected by the perception of self. Thus, the *Self-efficacy Theory* (Bandura 1997) primordial construct is that one’s capability to produce an adequate and effective behavioural response to a certain circumstance, producing a desirable outcome, is examined by oneself beforehand. Self-efficacy beliefs are said to differ in level, strength, and generality, whilst outcome expectancies from behaviour can be positive or undesirable, on physical, social and self-evaluation levels. This means that the contextual interpretation discussed is done from a self-awareness lens that examines if there is a risk, what type of risk and consequence, and finally, in the potential unfolding of a victimisation scenario if one would be able to protect oneself. Box, Hale and Andrews (1988), in agreement with this model, have also pointed the perception of risk and the potential seriousness of the offences as relevant for fear of crime to arise.

Following the self-efficacy premise, many studies have shown that fear of crime is higher in women (Bolger & Bolger 2019; Chadee et al. 2017), older people (Box, Hale & Andrews 1988; Rader, Cossman & Porter 2012), minorities (Bolger & Bolger 2019; Valente, Pertegas & Olmos 2019), people with lower socio-economic status (Vauclair & Bratanova, 2017; Valente, Pertegas & Olmos 2019), and lower educational level (LaGrange & Ferraro 1989; Scarborough et al. 2010). Individual characteristics play a role in the evaluation of the environment and its later reporting. Gender-wise, responses to survey items mirror gender role expectations rather than actual cognitions or emotions. Moreover, in addition to these individual predictors, there are said to be contextual cues that contribute to fear of crime.

Newman (1975), suggested guidelines to design the residential space to promote a sense of security through ownership of space. This agrees with the premise that the heightened capability to control an outcome in a given space, increases self-efficacy believes and therefore, lessens vulnerability and fear. Some of these urbanistic suggestions were for example the lighting improvement, which potentiates the possibility for surveillance or to delineate private and public spaces clearly, using gates or fences. This idea of territoriality by the community has been shown to influence the decrease of fear of crime. The higher an individual is integrated into their community (Klama & Egan 2011) and familiar with the neighbourhood (Roman & Chalfin 2008), the lower is fear of crime.

On the other hand, the broken windows theory (Kelling & Wilson 1982) focuses how the maintenance of the public space is perceived as a signal of social informal control and cohesion. This theoretical construct is that the public space that evidence litter, graffiti and other signs that might be interpreted as disorderly, is perceived as socially uncontrolled and as a spatial generator of further uncivil behaviour. This assumption is verified by many studies on fear of crime that have found that collective efficacy and mastery to be relevant to lower fear of crime levels (Hardyns, Pauwels & Heylen 2018; Boateng 2019).

Finally, Appleton (1975) drawing from the primal human need for safety, suggests that landscape can induce anxiety. In the case of an urban landscape, it does so when there are elements designed that (1) difficult the assessment of the space and possible threats and, (2) facilitate the hiding of potential offenders. To be seen and see is, thus, essential. Nasar and Fisher (1993) have conducted an *in loco* survey, considering three particular locations of the Ohio State University campus, during daytime and after-dark, which sought to investigate the effect of the prospect-refuge urbanistic aspects in fear of crime and spatial behaviour. A total of 258 people were surveyed. It was verified that fear increased in the areas with higher concealment spaces and lower prospect. This poorer prospect usually was associated with insufficient lighting. Also, the researchers reported that this affected behaviour, namely promoting avoidance or defensive behaviours.

Thus, the environment is usually scanned by people for potential danger and the surroundings might elicit risk readings (Farrall, Gray & Jackson 2007; Foster et al. 2013). Numerous contextual cues might contribute to fear of crime. These environmental signals are the ones that derive from the design or maintenance of the space, such as the presence of signs of incivility (Kelling & Wilson 1982), or the presence of concealment areas in the architectural design (Appleton 1975; Nasar & Fisher 1993), the presence of poorly maintained areas (such as the presence of litter, graffiti or vacant deteriorated buildings, among others) (Newman 1975; Kelling & Wilson 1982) and the quality of lighting (Herbert & Davidson 1995; Painter 1996), among other. There are also social contextual cues that contribute to an ambient to be perceived as risky, such as signs of disorderly behaviour, preconceived evaluations of the area or its residents or the number of people around (Home Office 1989; Gray, Jackson, & Farrall 2011; Rader 2017).

The presence of any or numerous of these aspects is said to favour a reading of that context as disorderly and in which collective efficacy is low, thus increasing levels of fear of crime (Scarborough et al. 2010; Gray, Jackson & Farral 2010). Higher familiarity with the area (Roman & Chalfin 2008) and greater social integration into the community (Adams & Serpe 2000; Sargeant et al. 2017) are related to a decrease in fear of crime. Boessen et al (2017) found that social ties, such as trust and familiarity with neighbours, had a negative effect on fear of crime. Namely, there was a decrease in fear of crime of 7.5%, per each known person within 1.6 km from the person's house.

In a survey study conducted through the telephone in Los Angeles, which collected 1816 interviews, Adams and Serpe (2000) have examined the relationship between the perception of vulnerability, feeling fearful, social integration, mastery and life satisfaction. The results showed that the lower the access to economic, social and psychological resources, the higher fear of crime was. This supports the assumption that self-efficacy and mastery over the outcome and the space are relevant for the fear of crime phenomenon. Furthermore, it was verified that this perception of lack of control over potential victimisation consequences, promoted fear of crime, and impacted the quality of life of these individuals.

Literature also points out an effect from the previous victimisation on fear of crime (Box, Hale & Andrews 1988; Mesch 2000). This is explainable in the light of the Self-efficacy theory principles (Bandura 1997), which statuses that beliefs of self-efficacy are influenced by so-called performance markers. In the fear of crime scenario, this means that an individual might have perceived oneself as not vulnerable, however after suffering victimisation or hearing about the victimisation of a person in similar circumstances, these performance markers might have lowered the self-efficacy confidence. An experience of victimisation might heighten feelings of vulnerability in an individual that wouldn't perceive himself as such.

There is another relevant component to fear of crime: the behavioural. Following the previously presented conceptualisation of fear of crime, behaviour is understood as a consequence and symptom of the phenomenon. However, researchers argue that these behaviours might have a cyclic component, increasing the self-perceived belief of vulnerability (Rader, May & Goodrum 2007). These behaviours are commonly sectioned into avoidance and restrictive behaviours (Maxfield 1984). Such behaviours seek to limit the exposure to risk and thus the potential victimisation. Avoidance behaviours seek to evade certain contexts, as refraining from going out after-dark or going to certain places unaccompanied. Restrictive behaviours refer to any that seeks to increase defensibility, such as owning a watchdog, installing alarms or closed-circuit television in the house, or carrying a weapon. Additionally, the behavioural component of fear of crime is said to be predicted by the individual characteristics that heighten vulnerability (Hassinger 1985; Rader 2017).

Lastly, research evidences a so-called crime-fear paradox (Farrall, Gray & Jackson 2007). This means that the perceived potential risk does not follow the statistical trend of actual crime. In agreement with the indication that this phenomenon is a product of a personal understanding of the environment, it points out the importance of its study as independent from crime rates.

2.3. Summary

The study of the effect of road lighting on the perceived safety by pedestrians requires not only an awareness regarding technical variables, such as photometrics but also knowledge of cognitive processes, such as the internalisation and expression of these. The higher perceived safety of an environment translates into various socio-economic benefits (Foster et al. 2005; Lorenc et al. 2013; Department for Transport 2015; Yuan & McNeeley 2016). Road lighting has been widely said to produce an effect in increasing reassurance (Fotios, Unwin & Farral 2015; Bolger & Bolger 2019), however, as it is a sole component of a rather complex fabric, that presents continuous stimuli in diverse intensities to individuals, it is fundamental to separate its real effect from these other (e.g. sound, litter). Boyce et al (2000) proposed a day-dark approach, which is characterised by the study of an environment both during the day and after dark. This is because the key difference between both conditions is road lighting, and it can usually only make visible what is there to be seen during the daytime.

Every stimulus present in the urban tissue is interpreted individually, against an internalised model which will dictate the reaction to it. Thus, finding communalities can be challenging. In this light, fear of crime is defined as an individual perception of a context, which evokes an emotional reaction (e.g. anxiety) and is expressed in a behaviour (e.g. avoiding going out). There are a few constructs that influence the possibility of fearing for one’s safety (e.g. self-efficacy assessment). Due to the personal nature of the perception of safety, factors such as age, gender or cultural background might be predictive of the level of reassurance felt. From this individuality to the interpretation of environmental signals, such as road lighting, emerges the question if studying the perceived reality is as good as studying the reality.

There is some variance in results from previous research, which can be explained by the inconsistencies in methods across studies. For example, phrasing, number of questions, and sources have been shown to impact results. Methodological issues are, thus, discussed in the next chapter (Chapter 3).

Chapter 3. Methodological complexity of road lighting for reassurance research

3.1. Critical issue 1: measuring fear of crime

There are several challenges related to the measurement of fear of crime or reassurance. One of the most basal is rooted in its conceptualisation and the consequent phrasing used in surveys, which are the preferred measuring instrument in fear of crime studies. For decades fear of crime was viewed as an emotional reaction to a perceived risk of victimisation but measured solely as a cognition (Garofalo 1981). This section discusses how the question has been asked and its implications for the resulting research.

3.1.1. Conceptualisation and phrasing

Fear of crime measurement was often done by asking proxy questions. These are questions that tap into related constructs but do not use terminology that directly relates to fear of crime. This is the case of questions that pertain to feelings of safety, feelings of vulnerability or perceived risk. Examples of such items would be "*How safe do you feel being out alone in your neighbourhood*" (Wyant 2008), "*How often does worry about crime prevent you from walking someplace in your neighbourhood?*" (Roman & Chalfin 2008) or "*How likely do you think it is you will be a victim of (crime type) in the next 6 months?*" (Hinkle 2015). Hinkle (2015) has compared results for two proxy items regarding perceived safety and perceived risk and an actual item regarding fear of crime. Results, from this comparison, showed that levels of fear of crime were underestimated by these proxy items. Thus, this suggests that phrasing is relevant and that a true measure of fear should include an item with such wording (e.g., fearful, scared, afraid).

Previous research on fear of crime was, at times, discrepant in its results. One reason is that the phenomenon has been measured using different questions that do not necessarily measure the phenomenon as a whole, but rather diverse parts of it. Adams and Serpe (2000) have used independent scales to measure fear of crime and perceived vulnerability. This resulted in men scoring similar levels of fear as women, whilst assessing themselves as less vulnerable to crime than women. Women are commonly reported as more affected by fear of crime (section 2.2), but these findings might also be affected by the phrasing of the survey items of those studies. The use of several phrasing forms might explain the variance in results with regards to the significance of demographic variables, for example.

Following the principle that fear of crime is recognised as an entire process that is cognitive, emotional and behavioural (Gabriel & Greve 2003; Mesch 2000). These questions might not only be measuring a particular fraction of fear of crime, but also only a fraction of the process. This is because a question that phrases “Do you ***think*** that you are safe walking alone in your neighbourhood?” is cognitive, while a question that asks, “Do you ***feel*** safe walking alone in your neighbourhood?” taps into the emotional state. This is relevant because not always what the logical mind perceives portrays the emotional reaction. An illustrative example would be any so-called irrational fear that is translated into a phobia, for example, *agoraphobia*. The individual recognises that there is no logical explanation to fear going outside the house, however, an extreme emotional response might be provoked just by imagining this possibility. Thus, asking if one thinks that it is safe to walk outside, is not necessarily the same as asking if one feels that it is safe or if one would avoid doing so.

A limitation to most previous studies on fear of crime is that phrasing might not be adequate, and therefore resulting findings are not representative of an overall fear of crime but certain concepts within it. However, this might explain a certain degree of variance in reported findings, it queries if a sole question is sufficient to investigate a multi-dimensional concept.

3.1.2. The standard single item

The focus on a single item to measure fear of crime was pointed out as a limitation before (Box, Hale & Andrews 1988; LaGrange & Ferraro 1989). This is particularly relevant if the phrasing is not taken into consideration (section 3.1.1.). However, this is still a common approach (Rader, Cossman & Porter 2012; Boessen et al. 2017; Sargeant et al. 2017).

The historical reliance on a sole question to infer about fear of crime is linked to the convenience of using a secondary data source such as National Crime surveys. While this offers access to a larger dataset, which is supposed to be more representative, it also ignores the need to increase theoretical depth in survey practice. Often these are studies that are not exclusively focused on fear of crime, but rather on different topics related to crime, health or other social aspects. Also, these can be presenting analysis levels, such as:

- multi-national, as the *2014 AmericasBarometer survey* (Singer et al. 2019) or the *2008 European Social Survey dataset* (Barni et al. 2016; Vauclair & Bratanova 2017);
- national, as the *2009 Statistics Canada GSS* (Piscitelli & Perrella 2017) or the *British Crime Survey* (Box, Hale & Andrews 1988);
- regional, as the *2003 Philadelphia Area Study (PAS)* (Wyant 2008) or the *Social capital and Well-being in Neighbourhoods in Ghent (SWING) survey* (Hardyns, Pauwels & Heylen 2018).

This level consideration is likely to produce discrepancies in results due to urbanistic and landscape characteristics, distinct cultural backgrounds, and various crime rates across countries, regions and neighbourhoods, among other aspects.

Typically, these studies consider a single item that is frequently referred to as standard because it asks about perceptions or feelings regarding walking alone at night. Schnell and Noack (2016) have analysed the statistical reliability of using only such an item, concluding that it does not suffice the usual psychometric threshold. However, this is true for many surveys. Nunnally (1967, cited in Schnell and Noack 2016) suggests that values above 0.5 Cronbach alpha suffice for experimental and preliminary purposes but not to inform crucial decisions. Considering that fear of crime studies informed several policies this method ought to be refined.

LaGrange and Ferraro (1989) have indicated the need for a wider instrument, while Box, Hale and Andrews (1988) have suggested this to be a multiple-item scale that considered the cognitive dimension, but also the emotional by asking about worry or anxiety, and the behavioural. This would allow the possibility to understand the complex patterns in fear of crime and the role of the interaction of its parts.

Gray, Jackson and Farrall (2011) have suggested a frequency-based approach, using a standard item to account for the presence of fear and then if so proceed to ask frequency and intensity measures ("*In the past year have you ever felt worried…?*"; "*How fearful did you feel..?*") and behavioural questions. However, these authors have used the terminology "worry" to describe fear, which as previously discussed might not be portraying necessarily overall fear, but the emotional state involved in a manifestation of the phenomenon.

Following the conceptualisation and considerations did previously, a multi-item survey, should tap into cognitive, emotional, and behavioural components, as well as focusing on one proxy aspect or the overall concept by using correspondent phrasing.

In parallel, it is also a pointed-out limitation to fear of crime studies that most studies are not crime-specific or location-specific (Rader 2017).

Scarborough et al (2010) have considered items that are spatial and temporal specific to measure this fear while using the phrasing "*fearful*" (e.g., "How fearful are you of a) *being home alone during the day*, b) *being home alone at night*?"). The findings were reported to agree with the literature on this topic. Adams and Serpe (2000) have used a scale to measure fear of crime that considered used the wording "worry" and "afraid" but considered fear felt inside the house, in the neighbourhood and when away. These authors have also differentiated the perceived vulnerability from fear of crime, thus considering different items. Gender-based analyses generated results that came to shed light on the importance of using scales specific to micro topics within the fear of crime for a higher understanding of it as a whole. Findings showed that men self-reported as feeling less vulnerable but equally fearful as women.

Another commonly adopted approach is to use the standard item or a variation and complete it with additional items regarding spatio-temporal aspects, frequency, intensity, crime-specific fear (Wyant 2008; De Donder et al. 2013; Valente, Pertegas & Olmos 2019). Mesch (2000), on the other hand, to examine the effect of fear of crime in night-time routines has combined the questions from three cognitive assessments of three crime-specific potential victimisations (assault, robbery and burglary), then items regarding after-dark behaviour and finally, the perceived risk. Each category index was then reduced to a single score through performing an exploratory factor analysis (internal reliability of $\alpha = 0.89$). Assuming fear of crime as a multifaceted phenomenon, to produce an overall score that accounts for its facets, a few studies have incorporated the multiple questions into a single value (Mesch 2000; Chappel, Monk-Turner & Payne 2011; Chataway & Hart 2016; Piscitelli & Perrella 2017). This method is explained further in Chapter 4.

3.1.4. The measuring instrument

The study of fear of crime has been done through the use of surveys or interviews. This conventional assessment of fear of crime has been as convenient as frequently retrieved from a secondary source, such as the British Crime Survey (section 3.1.3.). There are some conveniences in using national or international surveys, such as access to a more representative sample of the population or not having to consider participant reimbursement or recruitment. Hence, as abovementioned, this has been one of the preferred data sources in the study of fear of crime.

Nevertheless, because secondary data sources examine many societal issues at the same time, these do not provide trimmed questions to the specific premise of the study of fear of crime. These sources usually use a single item such as "*How afraid would you be of walking in your neighbourhood alone at night*?" for inferences on it. As previously argued, there are many nuances to the fear of crime concept, that might not be accounted for if there is only one item, asking about a specific dimension. This is particularly problematic, if then results from items tapping into different dimensions are generalised to the complete concept. Some studies have tailored their surveys to their inferences, using either mail or telephone to deliver them (Adams & Serpe 2000; Rader, May & Goodrum 2007; Scarborough et al. 2010; Wyant 2008; Lai, Ren & Greenleaf 2017)

Questionnaires have been widely used in social sciences to investigate perceptions and feelings. However, the use of questionnaires is subjective as it relies upon the idea that subjects are self-reporting truthfully. This is an issue that is well illustrated by the example of variances in self-reported fear of crime between female and male participants. Gabriel and Greve (2003) have suggested that survey results tend to be biased in this sense due to the societal construct that men are not allowed to fear, while women are viewed as vulnerable.

This subjectivity is also present because the answers are personal and dependant on individual conceptualisations and experiences of the world (Vogt 2012). This means that perceptions might not be equivalent between subjects. For example, when asked if fearful at night in the neighbourhood, on a scale from 1 to 6 points, the significance of a 4 might vary in intensity between individuals. Also, there might be data variance that results from cultural differences in the survey sample. This is particularly relevant for the generalisation of data or comparison between studies. In the case of fear of crime studies, there are many incongruencies in the data, which could be rooted in minor changes in conceptualisation, data source and survey sample characteristics. In the absence of more objective measures, surveys are acceptable but should attempt at measuring the underlying dimensions of feeling reassured prudently, while considering phrasing, settings, and sample characteristics.

However survey research presents subjectivity of interpretation both from the participant and the data analysis standpoint, it is also a valuable method to measure perceptions, attributes, and even behaviour of individuals (Curtis & Curtis 2017). This is because it provides a non-intrusive mean of research of these aspects. Furthermore, perceptions and interpretations of life are subjective, thus it is also discussable if this subjectivity is not only a reflection of reality itself. Nevertheless, this subjectivity overcoming could be verified by measuring and inferring physiological cues, such as sweat response, heart frequency or gaze behaviour. Though, these measurements require expert equipment, thus likely limiting the number of participants.

3.2. Critical issue 2: the recalled or imagined darkness

3.2.1. The choice of setting: imagine darkness or experience it?

The study of the benefits of road lighting for enhanced perception of safety studies resorted to photographs, laboratory or sometimes *in loco* settings. Loewen, Steel & Suedfeld (1993) reported two studies that concluded that lighting promoted reassurance in people. The first study had 55 participants select from a list the environmental cues that were relevant to their perception of safety. The light was cited by 76.4% of the participants. So, to investigate the importance of lighting and prospect and refuge cues, a second study was carried out. Sixteen pictures with variations in lighting and open space and accessibility were presented using a projector to a hundred participants, who had to respond to a questionnaire about perceived safety. The slides were projected for 30 seconds. Results showed that lighting was the most significant variable and that its interaction with other variables defined their relevance. This evidences that visibility is relevant to feel safe. However, it is arguable that a projected slide can account for the real feelings or perceptions an environment can trigger. Thus, even though valuable results are identified concerning the recognition of environmental cues relevant for reassurance, it does not identify technical thresholds of lighting.

Presenting pictures for evaluation is a common method that provides a controlled environment and allows the testing of many participants. Nonetheless, the use of photographs limits the drawing of conclusions regarding lighting and the overall experience of the environment. This is because the lighting is processed sensorily in the eye (Boyce 2014). Thus, while cameras mirror the processing of light by the human eye, for example, through the manipulation of aperture, images lack the personal sensorial experience, which is dependant on physiological individual characteristics.

Therefore, one fundamental limitation is that researchers can only measure the relationship of perceived brightness and not actual light levels to safety assessments. Another is that by using images, individuals are being asked to imagine how they would feel in such a place (section 3.2.2.). However, laboratory settings also present advantages, as these allow the control of conditions and the simulation of intended circumstances (Miller & Salkind 2002). An example of such application is the study of lighting for obstacle detection (Fotios & Cheal 2010; Uttley, Fotios & Cheal 2017), where participants can be tested in a few manipulated conditions, in a highly time-efficient manner. Curtis and Curtis (2017), nonetheless, point out that laboratory settings could influence participant behaviour. This is a particularly relevant issue in the study of lighting and reassurance, as laboratory settings could limit perceptions of risk, for example.

Research about the urban environment and reassurance, ideally, should take place in it. However, field studies might (1) be time-consuming, lowering the possible number of test participants and environments, (2) present unpredictable stimulus or difficult manipulation of desired variables, constraining maximum experimental control, and (3) require equipment or other resources funding. The sample size limitation potentially decreases the representativity and generalisation of findings.

In the case of the study of lighting its biggest challenge would be finding a range of lighting conditions in roads with similar urbanistic to exclude the interference of other aspects. Field studies have been mainly carried out to study lighting in car parks (Boyce et al. 2000; Narendran, Freyssinier & Zhu 2016; Bullough, Snyder & Kiefer 2019). Car parks present low urbanistic detail and lighting levels can offer the variation needed or be manipulated to. The manipulation of lighting levels, in car parks, also provides a solution for having to bring participants to different sites. Although laboratory settings have been privileged in the study of road lighting, some studies carried out studies *in loco* (Fisher & Nasar, 1992; Mattoni et al. 2017). For the *in loco* study of lighting, the selection of real roads demands either the measurement of lighting levels experienced in each in advance (Mattoni et al. 2017) or other forms of evaluation, such as the control of the illuminances or the distributions (Blöbaum & Hunecke 2005; Haans & Kort 2012).

3.2.2. Asking to recall or imagine darkness

The standard single measure is "*How safe is it to walk alone in your neighbourhood after dark?*" or an adaptation of this. As previously demonstrated, this is the item responsible for a representative share of fear of crime studies. Drawing from the premise that phrasing is essential for accurate survey use, the implications of the use of the phrasing *after-dark,* for the results, is worth examining.

The most common methods used for data collection in this topic are either administering a survey through the telephone (e.g. Adams & Serpe 2000; Mesch 2000; Rader, May & Goodrum 2007; Wyant 2008; Lai, Ren & Greenleaf 2017; Valente, Pertegas & Olmos 2019), mailing it (e.g. Hassinger 1985; Scarborough et al. 2010), or retrieving data from larger datasets (e.g. Stafford, Chandola, & Marmot 2007; Hanslmaier 2013; De Donder et al. 2013; Barni et al. 2016; Singer et al. 2019). A few studies have used laboratory settings (e.g. van Rijswijk, Rooks & Haans 2016; Boomsma & Steg 2014; Nasar & Bokharaei 2017) and other fewer studies interviewed individuals *in loco* (e.g. Nasar & Fisher 1993; Lee, Park & Jung 2016). This means that predominantly studies are focused on after-dark potential fear of crime, disregarding daytime. Semantics have a representational meaning which not only requires knowledge (Fairlough 2003) but also introduces an experiential meta-function (Halliday 1994). The use of such semantic representation ("at night") is likely to be inducing certain reasoning (Heit 1997). Thus, fear of crime is portrayed as a time-framed phenomenon, which is not necessarily real, but a perceived potential. Along with this limitation, this phrasing also asks participants to either recall or imagine darkness.

The mostly adopted methodology, thus, usually asks subjects to remember a situation, such as walking alone after-dark. Memory is said to store perceptual information, gathered through experience, that is later generalised to perceived similar experiences (section 2.2.1.). Thus, memory serves a functional purpose to individuals. This explains different environmental interpretations between different individuals. In a risk evaluation of a specific context, a subject will draw from memory previous past events in similar contexts and apply that retrieved experience.

According to a proposed memory error taxonomy by Michaelian (2016), there are possible memory errors that affect accuracy, reliability, and the internal representation of that recalled situation or object. Successful remembering happens when information is retained accurately. Many psychological factors could influence the capacity to retain information and rely on memory. Two phenomena, relevant to this section, might be observed: *Misremembering* or *Confabulation*. The first refers to when information is recalled but inaccurately, the latter refers to a process when an imagined narrative is built, felt, and presented as real (Michaelian 2016).

Considering that remembering successfully is dependant at least on accuracy, reliability, and the internal consolidation of that information, one could detect a validity issue of defining a multifaceted phenomenon, such as fear of crime, based on such item. For example, considering that daily travel patterns tend to be mechanical and purposeful in moving from the main node to another, such as from home to work. Then, it might be that an individual has a slight motivation to move after-dark, uses a car to do so or does not take strolls after-dark in the neighbourhood. This would determine their capacity to answer a question regarding walking outside after dark.

Collins (2016) has conducted a meta-analysis to evaluate how this phrasing (after dark or night-time) produced variable results. It was found that asking if someone feels safe walking somewhere alone generates a relevant change in the self-reported fearful population compared to when the question adds the phrasing “at night”. Walking alone somewhere reported a strong relationship between fear of crime and the variables race, education, victimisation experience and police satisfaction. While walking alone at night informed a stronger relationship between fear of crime and gender, but a weaker relationship between fear of crime and education, victimization experience, the presence of physical incivilities and the satisfaction with the police. This indicates that fearing for one’s safety is dependant on the given conditions.

An example of the importance of considering that recalled darkness might not be portraying the actual feelings or perceptions during after-dark hours is a study carried out by Lee, Parks and Jung (2016). This study aimed at investigating the effects of Crime Prevention through Environmental Design measures on fear of crime and walking frequency in Seoul, Korea. For this purpose, the authors used an *in loco* approach and asked transients to answer a survey on a smartphone application. Results showed that sufficient lighting was negatively correlated with walking frequency. However, surveys were carried out between 10 am and 3 pm, which is a time of the day when it is unlikely to be necessary any road lighting, due to sufficient sunlight. So, not only it is unlikely to be any lighting on, but also participants might have never experienced those particular streets in an after-dark setting.

Asking questions about an imagined possibility is a limitation of studies that are not *in loco*. However, this could be tried to be accounted for through, for example, asking participants to rate both daytime and after-dark scenarios. A few studies have considered daytime and after-dark similar items, for example, “*How fearful are you of being home alone during the day/at night?*” (Scarborough et al. 2010), “*How safe do you feel being out alone in your neighbourhood during the day/at night?*” (Lai, Ren & Greenleaf 2017) or “*I am afraid to walk in my neighborhood at day time/at night-time*” (Boateng 2019). The results are typically conveyed as an overall score, so it is not possible to infer the differences between self-reported daytime and after-dark fear.

In a study focused on understanding the relevance of temporal and spatial distinctions for fear of crime, Boessen et al (2017) looked at fear of crime during the night; during the day and the difference between night and day expressed fear of crime. It has used the standard item measure, however addressing both temporal conditions, having identified a significant difference in the levels of fear of crime. These results corroborate the premises discussed in this section, however, more research on the effect of imagined darkness in survey results would be desirable.

3.3. Critical issue 3: Implications of evaluating environments only after dark

The urban tissue presents auditory stimulus, diverse spatial arrangements, the presence, or absence of so-called incivility cues (e.g., litter, graffiti) and varied traffic flows, among other (section 2.1.). Road lighting is a single aspect of a rather complex urban fabric. It can only promote the level of safety felt during the daytime. Also, rather than reaching daytime light conditions, it can only aim at being optimal in providing an artificial form of lighting. The main issue with only evaluating lighting conditions during nighttime is that it will remain uncertain if the observed effect is due to lighting or other aspects. Lighting can only illuminate what is there to be seen.

The common result from such evaluations is that the highest illuminance is always better (Atkins, Husain & Storey 1991; Peña-García, Hurtado & Aguilar-Luzón 2015). This conclusion implies a range bias provoked by the range of illuminances available at those studies and possibly the order in which these were presented (Poulton 1977). However, the alternative approach to the study of road lighting contribution to safety appraisals proposed by Boyce et al (2000), not only accounts for other landscape elements, but also by doing so allows the researchers to identify an optimum lighting threshold. Other studies have recognised the methodological importance of collecting both daytime and night-time appraisals from participants. Lai, Ren and Greenleaf (2017) also asked participants regarding their perceived safety when being alone in the neighbourhood during daytime and at night separately. This demonstrates a recognition that the same environment is likely to be experienced differently during the day and at night. This is likely to be due to variance from natural to artificial lighting. Similarly, Valera and Guardia (2014) in a study with 571 participants in Barcelona have collected data between 10 am to 1 pm, 4 to 7 pm, and 8 to 11 pm. However, the data were clustered through factor analysis, making it impractical to draw any consideration on-road lighting, as at least during two conditions road lighting is unlikely to be on for the full session.

Calculating the difference between assessments of a road in the daytime and after dark has been used by Boessen et al (2017). Participants were asked about the fear of crime felt during daytime and after-dark separately and the differences between both conditions were considered. However, only the means of these ratings are reported, ranging from very safe to very unsafe in a 5-point Likert scale, the highest meant people felt more unsafe (daytime $\bar{X}$=0.37; night-time $\bar{X}$=0.97; night-time to daytime change $\bar{X}$=-0.65). Nevertheless, if daytime averaged scores are not null, it means that the locations or areas inquired about are not perceived as completely safe during the daytime. Bearing in mind that artificial lighting can only aim at the daytime threshold of safety feelings, these results are meaningful to confirm that Boyce et al (2000) approach are likely to result in more significant findings.

While the proposed day-dark approach (Boyce et al. 2000) is likely to produce more significant results, because it establishes a baseline for the reassurance felt during daytime and allows later comparison of the after-dark recorded level, it presents some disadvantages. The main assumption of this method is that the day and after dark usage of urban tissue is the same. This is very often the case, particularly in residential areas. Nevertheless, there are urban areas that have diverging usages and users in either condition. An example would be a city centre, which during the day might encompass professional, service, and commercial use, while at night could be transformed to leisure. Furthermore, this method does not account for the presence of other aspects such as auditory stimuli, the difference of pedestrian flow or change in the participant state of mind, which could influence attention to the experiment.

3.4. Critical issue 4: Lighting levels methodological inconsistencies

Another common limitation of the study of the role of lighting for crime prevention or in fear of crime is the lack of technical rigour. Many studies that informed policy did not report the lighting levels or how these were measured (Atkins, Husain & Storey 1991; Painter 1996; Painter & Farrington 1999).

Painter and Farrington (1999) carried out a study in the UK using victimisation surveys 12 months before and after the relighting of an area. There are several limitations to this study, which mirror those of other studies across lighting and reassurance research:

(1) Although there is a reference to the light sources used for the relighting project and that the average illuminance was 6 lux and a minimum of 2.5 lux (meeting, as expected in 1999, the BS 5489, Part 3), it is unlikely that every street relit presented the same average and minimum.
(2) There is no mention of the previous lighting levels. Thus, findings could be solely resulting from the perception of intervention in the space itself.
(3) There is a mention of uniformity, but this value is not reported.
(4) The surveys were directed at residents, who at times moved out of the neighbourhood. In this case, new tenants were asked instead. Thus, this

study design follows neither within-subjects nor between-subjects design, which demonstrates methodological inconsistency.

(5) It is unclear how residents felt about the neighbourhood during the daytime. So, it might be that fear of crime has no significant relationship with lighting.

(6) The criminality rates are not gathered from police reports, but apparently from the victimisation surveys. The "*respondents were asked whether they, personally, knew anyone else from their estate who had been a victim of specified crimes in the last year*" (Painter & Farrington 1999). This is an issue because individuals' memory can be distorted, placing events out of the 12-month window in it and some participants might even confabulate events (section 3.2.2.).

(7) Finally, the pedestrian count was done in only two days before and after the relighting projects, which ignores patterns of at least five other weekly days.

The application of surveys before and after relighting projects was a common methodology for the study of lighting and fear of crime (Davidson & Goodey 1991; Farrington & Welsh 2002). However, the studies lacked the before and after light levels (Painter 1996), the statistical significance of the data (Atkins et al. 1991) and some reported values that made replication or comparison of results challenging, such as reporting the bulb watts (Morrow et al. 2000) or that the lighting levels were improved by 3 to 5 times without stating the illuminance starting or ending point (Welsh & Farrington 2008).

The resuming of a whole neighbourhood, which is likely to present various lighting conditions and urbanistic different aspects per street and that might not be necessarily known by its residents is also a limitation. Living in an area does not inevitably mean that you are its pedestrian user. Thus, there is no guarantee that residents are acquainted with the area the researchers are enquiring about. The perception of the neighbourhood limits is likely to differ between researchers and residents and within residents. As observed in Florence Ladd study (1970, cited in Canter, 1977, p.12) the spatial representation of neighbourhood is individual and dependent on the daily experience of those spaces.

3.5. Research aims and objectives

The studies reported and discussed in this thesis is focused on pedestrians' feelings of reassurance when walking after dark in an environment. The relationship between safety feelings and road lighting has been used to guide international standards and urbanistic interventions for crime prevention. However, it remains unclear which photometrics have a greater effect in reassuring pedestrians and which is their optimum level threshold. This uncertainty can be partly not only due to the psychosocial nature of perceptions and feelings of safety but also due to inconsistent methodology throughout research.

Following the discussed methodological issues (section 3.1. to 3.4.) and questions raised by the literature review, nine questions to be investigated were determined. To investigate and answer these questions, two field studies were carried out – one in 2016 and another in 2018 - using surveys to collect reassurance appraisals from participants. The questions, a summary of how these were addressed and where, in this thesis, this is reported is presented in Table 3.

Table 3. Summary of research questions, how these are addressed and in which chapter

	Question	How will it be addressed	Chapter
1	Is Boyce et al (2000) day-dark approach better than just evaluating after-dark scenes?	Participants were asked to evaluate the same test locations in the daytime and after dark. Results from day-dark differences and after dark assessments are examined.	Chapter 4
2	Are single items enough in portraying the fear of crime-reassurance feelings?	A questionnaire was designed for this research, using the classical standard item, and a set of questions that consider the emotional and behavioural components, allowing a comparison between both methods.	Chapter 4
3	Which lighting metrics reassure pedestrians?	Horizontal, Hemispherical and Semi-cylindrical illuminances were measured in the chosen test locations. The minimum, maximum and uniformity are also considered. Test locations were determined aiming at offering a range of illuminances for the studies. The safety perceptions in the locations are looked at. Study 1 is reported in chapter 4 and study 2 in chapter 5.	Chapter 4-5
4	What is the optimum level of those metrics?		
5	Is there a quantifiable impact of imagination or re-called after-dark scenarios that might have affected	A question that uses the phrasing “after-dark” is included in the questionnaire both during daytime and after-dark.	Chapter 6

	previous results?		
6	Does asking about perceived brightness provide a similar result to analysing measurable lighting metrics?	Lighting metrics and the perceptions regarding the lighting on spot are analysed considering participant ratings regarding overall quality, glare, among others.	Chapter 6
7	Conclusion	Conclusions are drawn, limitations identified and recommendations for further research provided.	Chapter 7

The effect of other stimuli present in the environment was isolated by applying the day-dark approach (Boyce et al. 2000). Furthermore, range bias avoidance was attempted with counterbalanced routes, in which locations were visited in different orders, and by having different starting sessions, some participants had a first contact in the daytime and some after dark. Stimulus range bias is defined as the influence of the presented range of experimental stimuli in subjective appraisals (Kent, Fotios & Cheung 2019). Thus, by counterbalancing the exposure to the lighting conditions through the presented order and the starting sessions a reduction of potential bias of the range is sought. However, the complete exclusion of range bias is unlikely as this is a field study, and participants experience numerous lighting conditions in between test locations.

This research aims at experimenting with a different approach to the study of road lighting and reassurance and, in doing so, addressing, and examining the limitations of previous studies.

3.6. Summary

Due to the complexity of the elements involved in such study, methodologies should weigh benefits concerning (1) the choice of setting (e.g., lab, on-field study) and (2) the method for data collection (e.g., surveys, physiological measures). Each methodological setting provides benefits and shortcomings that should be considered in the research design.

An important consideration is a sufficiency of using a single question to investigate a multi-dimensional concept, as fear of crime (section 3.1.2). If the instrument selected for data collection is a questionnaire, as in the present research, considerations on phrasing should be made. This is because the phrasing has the power to both suggest or measure underlying constructs that could not necessarily represent the topic under analysis (section 3.1.1). An example of this is the use of the phrasing "*after-dark*" in fear of crime studies. This might suggest the participant to imagine or recall the level of darkness in a place, however, the ability to do this accurately is likely to be low (section 3.2). Thus, conclusions regarding after-dark actual perceptions, feelings or behaviours might not be as precise as when that environment is experienced.

Evaluating only after-dark environments is also a critical issue because urban settings are a complex tissue that is flooded by stimuli and road lighting is only one (section 3.3). Road lighting can only aim at the safety perception felt during daytime in the same location. So, it is crucial to adopt a method that isolates potential effects of stimuli other than road lighting. Boyce et al (2000) suggested that the day-dark approach generates results that effect only relate to road lighting, by looking at the difference between safety appraisals during daytime and night-time. There are limitations to this method as discussed in this chapter. The final limitation of fear of crime and road lighting studies is the imprecision observed in the lighting levels report.

Although, questionnaires will be used in the experiments reported in the next chapters, the effect of using a single question versus using multiple items that consider various dimensions will be looked at. Assessments will be carried out by participants while experiencing the atmosphere at test locations, both daytime and after-dark. Moreover, the main goals of this research are to verify if there is an observable relationship between road lighting levels and reassurance in pedestrians and reported crime. Chapters 4 to 7 report and examine the results from two experiments.

Chapter 4. Field study 1: What is the optimum illuminance to reassure pedestrians?

4.1. Introduction

This chapter focuses on an exploratory study of the relationship between reassurance in pedestrians and road lighting in residential roads. Road lighting standards define a set of lighting metrics and the recommended minimum values for these metrics. However, it is unclear if these are the optimal levels or how are these associated with heightened reassurance. Additionally, previous studies of road lighting and perceptions of safety have presented some limitations such as relying on only one rating item (section 3.1.2), evaluating locations only after dark (section 3.2.2.), the choice of setting and the lighting metrics reported (section 3.2.1 and 3.2.3.). Thus, field study 1 attempted to explore four hypotheses:

1. Reassurance ratings determined after-dark are not significantly associated with mean horizontal illuminance.
2. The reassurance day-dark appraisal difference is significantly associated with mean horizontal illuminance.
3. The day-dark difference is better associated with minimum illuminance or illuminance uniformity than with mean horizontal illuminance.
4. A composite rating accounting for multiple dimensions of reassurance expresses a better association with illuminance than a single survey item.

4.2. Method

The effect of road lighting on pedestrian reassurance was investigated through a field study. A set of residential roads was selected, and later these were visited by participants during daytime and after dark. Thus, the day-dark approach (Boyce et al. 2000) was used. By recording ratings in both conditions, the day-dark difference can be calculated, providing the relative importance of road lighting in that location.

4.2.1. Test locations

Field study 1 was carried out in a residential area in the city of Sheffield in the United Kingdom in 2016.

The choice of locations to test was based on three main practical considerations – (1) proximity to the University of Sheffield building the Arts Tower, the starting point for the field study trials; (2) the range of illuminances; and (3) the urban morphology. As this research was undertaken *in loco*, locations needed to be close to the university premises and between themselves, to reduce the walking time. Moreover, to understand the effect of illuminance levels on perceptions of safety, the locations had to provide a variance in the illuminances. A third aspect that contributed to its selection was the urban landscape similarity or diversity offered to the study.

Thus, ten test locations were selected in the *Netherthorpe* neighbourhood of Sheffield (Figure 2). These were eight residential roads (R1 to R8), one pedestrian footpath (R9) and one underpass footpath (R10) (Appendix A). The footpath and the underpass were included to act as a control, as these provide different urbanistic features to the eight residential roads. This differential is regarding the extreme lighting level provided in the underpass and the conditions of entrapment and prospect. This would allow to enhance potential ranges bias, and identify potential differences derived from the Appleton premises. Table 4 shows the general urban morphology of these locations.

Figure 2. Map of the area of Netherthorpe in Sheffield with the test locations highlighted.

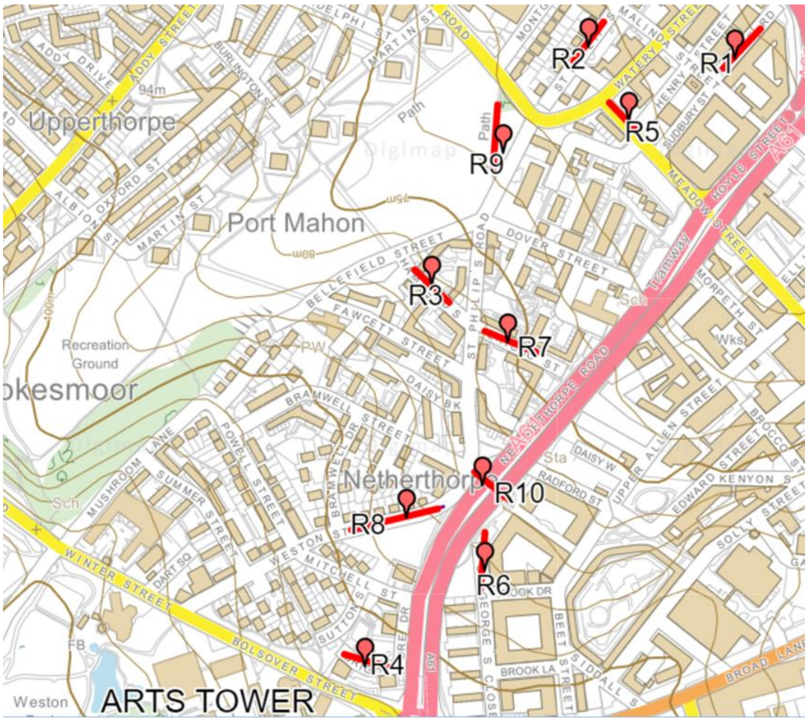


Table 4. Urban morphology of chosen test locations

*The term “terraced” refers to housing that share a wall, while the term “flats” refers to a residence located in a building occupied by more than one household.

Road	**Type of Road (UK Classification)**	**Pedestrian pathway**	**Class of Street according to lighting**	**Type of buildings***	**Street Parking**	**Presence of Trees**	**Open space**
R1	Unclassified	✓	S3	Flats	×	×	×
R2	Unclassified	✓	S2/S3	Terraced	✓	✓	×
R3	Unclassified	✓	S6	Flats	✓	✓	×
R4	Unclassified	✓	S5	Flats	✓	×	×
R5	Classified	✓	S2	Flats	×	×	×
R6	Unclassified	✓	S5/S6	Flats	✓	×	×
R7	Unclassified	✓	S3	Terraced	✓	×	×
R8	Unclassified	✓	ME3C	Terraced	×	✓	×
R9	Pedestrian: park pathway	Not applicable	Unknown, but there are lamps	No buildings	×	✓	✓
R10	Pedestrian: Underpass	Not applicable	Unknown, but there are lamps	No buildings	×	×	×

The morphology of the locations varies slightly in terms of the type of buildings present in R1 to R8, while R9 provides a wide prospect due to being a park pathway (Figure 3), and R10 is an enclosed space (Figure 4), which could be perceived as entrapment. The last two locations (R9 and R10) were included to examine if differences were detected in different urbanistic settings, while R1 to R8 offer a residential setting. Considering that this study was carried out in a real-life scenario, minor differences in the architectural landscape had to be expected.

Figure 3. Park footpath during daytime and after-dark (R9).

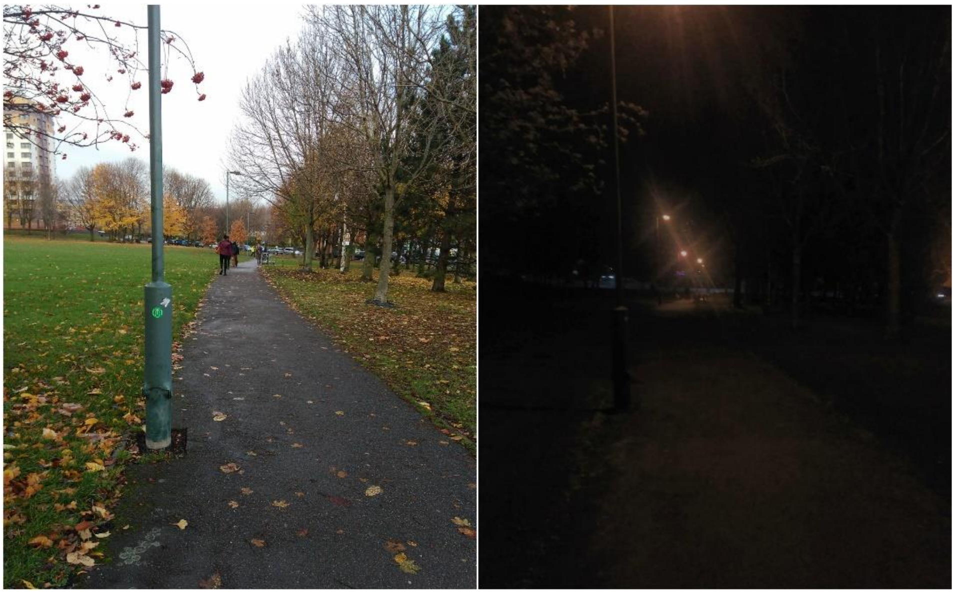


Figure 4. Pedestrian underpass during daytime and after-dark (R10).

4.2.2. Photometric values

Three lighting metrics were assessed in the test locations – horizontal illuminance, hemispherical illuminance, and semi-cylindrical illuminance. To measure and record these illuminances, an apparatus was taken to the locations. This apparatus was a bicycle trailer, with three photometers mounted and connected to a data logger (HOBO 4-channel analogue logger, UX120-006M), and an odometer connected to one wheel of the trailer and another data logger (Appendix B). This odometer was also connected to an external button, used to mark the locations into the data logger, when pressed. By doing so, it was possible to collect the distance between lamp poles and to identify the lighting measurements corresponding to each road segment. Three photometers (Hagner E4-X) were used to measure the illuminances; using the detector SD11 for semi-cylindrical and the detector SD10 for hemispherical illuminance. The SD11 sensor was mounted according to the BS EN 13201-3:2015 guidance at a height of 1500 mm above floor level, measuring illuminance in the vertical plane and facing the pedestrians' direction of travel. On the other hand, due to the measurements being taken synchronically in a continuous movement, the hemispherical and horizontal sensors were not at ground level but instead were at a height of 150 mm and in the horizontal plane. The recorded data was adjusted, in agreement with the manufacturer's instructions, by multiplying by the correction values of 1.961 (semi-cylindrical) and 0.882 (hemispherical).

Lighting levels were recorded in the centre line of both pathways, between the two lamp poles marking the ends of the chosen segments for the experiment. The apparatus recorded data points every 3 seconds into the logger. From this continuous recording, 10 equally spaced data points in each side of the segment were chosen to later determine the lighting levels (average, minimum, maximum and uniformity), in a total of 20 measurement points (R1 to R8). For the park footpath (R9) and the underpass (R10) only a set of 10 data points were used.

These measurements were recorded after-dark on two occasions (13th and 20th March 2017). Table 5 summarises the conditions under which the lighting measurements were carried out – date, starting time of measurements, sunset time, moon phase and weather conditions.

Table 5. Date and conditions during lighting measurements.

Date	Time commencing measurements	Sunset time	Moon phase	Weather conditions
13th March 2017	19:00	18:07	Waning Gibbous (Illumination 98%)	Cloudy and dry
20th March 2017	19:00	18:20	Waning Crescent (Illumination 39%)	Cloudy and rainy

There was a good degree of consistency between the two measurement datasets, evidenced by the high linear association between both for N=180 (horizontal illuminance R^2=0.95; hemispherical illuminance R^2=0.96; semi-cylindrical illuminance

R^2=0.94) (Appendix D). An averaged lighting value between both datasets from each measurement point was used. The averaged photometric values resulting from both evenings are reported in Table 7. These are the values used in the data analysis. Furthermore, the mean illuminance is calculated as the arithmetic mean of the 10 equally spaced measurement points (BS EN 13201-3:2015).

Considering the mean value for all illuminances and the 180 data points a high degree of correlation is verified between the metrics (Appendix D). Excluding the R10 location, due to extreme values of illuminance (Table 6), that led to a R^2 = 0.99 in each pair, considering the mean values for each location correlate as follows: horizontal *versus* hemispherical illuminance show a R^2 = 0.93, horizontal *versus* semi-cylindrical illuminance, R^2 = 0.83, and hemispherical *versus* semi-cylindrical illuminance, R^2 = 0.84. Considering N=176 (excluding 4 extreme data point outliers) a high degree of correlation is also evident: horizontal *versus* hemispherical illuminance, R^2 = 0.95, horizontal *versus* semi-cylindrical illuminance, R^2 = 0.87, and hemispherical *versus* semi-cylindrical illuminance, R^2 = 0.96. The degree of correlation between metrics suggests that considering only the horizontal illuminance is acceptable.

Moreover, it is important to mention that the ten roads used different light sources - High-Pressure Sodium (HPS), Metal Halide (MH), LED arrays and Fluorescent (Table 6). Although variations in lamp spectra might have an effect on reassurance assessments (Knight 2010) the effect is expected to be smaller than that of changes in illuminance, hence light source is not the focus of the present research. The road lighting was single-sided in eight locations except for R7 in which the lamps were staggered. The underpass (R10) was lit on both sides. In R3 there was some illumination from external lighting on buildings on the far side of the road to where the evaluation sheets were filled in.

Table 6. Test locations coordinates and lighting characteristics.

Site	Coordinates	Type	Lighting configuration	Lamp type	Distance between lamps (m)	Distance walked by observers (m)	Horizontal illuminance (lux)		Hemispherical illuminance (lux)		Semi-cylindrical illuminance (lux)	
							Mean*	Min*	mean	min	mean	min
R1	53°23'18.4"N 1°28'45.2"W	Residential Road	Single sided	Metal Halide	34.3	95	7.5	1.3	5.1	1.4	4.2	0.7
R2	53°23'19.0"N 1°28'53.3"W	Residential Road	Single sided	HPS	34.0	79	4.2	0.5	3.0	0.9	2.6	0.8
R3	53°23'10.4"N 1°29'00.8"W	Residential Road	Single sided	HPS	30.2	85	10.6	3.2	9.1	3.7	7.5	3.8
R4	53°22'58.1"N 1°29'04.2"W	Residential Road	Single sided	HPS	36.7	82	9.1	3.1	6.8	3.3	6.5	3.7
R5	53°23'17.5"N 1°28'51.8"W	Residential Road	Single sided	LED	39.2	101	8.5	3.5	6.4	2.7	4.2	0.7
R6	53°22'57.8"N 1°28'59.0"W	Residential Road	Single sided	LED	24.2	94	7.2	4.0	5.4	4.1	4.1	1.5
R7	53°23'09.4"N 1°28'59.3"W	Residential Road	Staggered	HPS	23.2	88	6.9	1.8	5.0	2.1	2.8	1.8
R8	53°23'02.7"N 1°29'07.3"W	Residential road	Single sided	HPS	30.3	101	5.0	1.2	3.6	1.4	2.1	0.8
R9	53°23'14.9"N 1°28'58.3"W	Park pathway	Single sided	HPS	29.1	66	7.7	1.1	4.9	1.3	4.0	0.7
R10	53°23'04.7"N 1°28'59.5"W	Underpass	Opposite	Fluorescent	30.1	57	58.2	28.5	58.5	31.5	55.2	25.8

* Reported uniformity is based on these values.

4.2.3. Sample

Twenty-four participants were recruited using the university mailing system. This sample was gender-balanced (12 female and 12 male participants) to attempt at balancing possible gender bias.

The participants had a mean age of 24 years, ranging from 18 to 38 years old. Visual acuity was self-reported in the consent form (13 participants reported not to need corrective lenses, 5 wore corrective lenses for far tasks, 3 for near tasks and 3 for both near and far tasks). The sample was multi-cultural, even though the UK held the highest representation (11 participants). Four participants had European nationalities, four Asian nationalities, including the Middle East, three South American nationalities, one African nationality and one Australian nationality.

The sample power was estimated considering the sample size of previous safety and road lighting studies (Nair, Ditton & Philips 1993; Boyce et al. 2000; Boomsma & Steg 2014; Rea, Bullough & Brons 2017), and that a repeated measures design, such as the day-dark approach was applied. Sample power is fundamental to estimate the number of participants needed for an acceptable generalisation of results. This analysis assumed an alpha of 0.05 and a power of 0.8, using a repeated-measures ANOVA. A size effect of 0.18 (Cohen's f) was predictable, which is considered a medium-size effect in the Cohen categorization (Cohen 1992). The size effect indicates the amount of potential bias of the measurement of variance explained, for example by R^2, underlying in data. Thus, the effect size is a statistical measure of the strength of the association between variables (Salkind 2010).

4.2.4. Questionnaire design

The questionnaire was designed to measure the cognitive, emotional and behavioural dimensions of reassurance considering the time limitations related to multiple field assessments in a session. The use of multiple questions to measure reassurance in a local is likely to minimise participant misinterpretation and increase construct measure reliability. Furthermore, a set of questions regarding the observable environment was included, including regarding to lighting in the after-dark version.

The daytime version of the questionnaire had ten questions; the after dark version considered five additional items related to road lighting. Four questions evaluated the reassurance components: cognitive ("*How risky do you think it would be to walk alone here at night?*", "*How safe do you think this street is?*"), emotional ("*How* *anxious do you feel when walking down this street?*") and behavioural ("*I would rather avoid this street if I could*"). The questions assessing the cognitive dimension are analogous to the ones used by Boyce et al (2000) in a study in parking lots. However, in the present chapter, the item assessing risk was excluded from the analyses. This was because it used the phrasing "at night" (see 3.2.2) in both after-dark and daytime conditions. This meant that while other survey items addressed the daytime and after-dark conditions, the risk item was always related to an after-dark context.

There were five contextual items ("*I can see clearly around me*", "*Apart from the researcher and any other participants, there are lots of other people on the street*", "*This street is kept in good condition*", "*I can see a lot of litter and rubbish on this street*", "*How familiar are you with this particular street?*") and a question to evaluate attentiveness (Appendix C).

A single question to check attentiveness, or bogus question was included per questionnaire (Meade & Craig 2012), and it was chosen randomly from a pool of sixteen questions (Figure 5). Meade and Craig (2012) define a bogus question as one that every participant should be able to answer in the same manner. For example, "*I have never been to Sheffield*" should be answered as "*strongly disagree*", as the participants were assessing locations in Sheffield.

Figure 5. The pool of 16 bogus questions.

I was born after 1879
I shower more than once a month
I have never been to other planets
I own a pen
I am wearing clothes
I usually sleep more than one hour per night
I have watched a film at least once in the last 10 years
I have visited every country in the world
I always walk barefoot in the street
I have never seen water
I speak 35 different languages
I eat cauliflower every day
I never had a cold
I personally met Shakespeare
I have never been to Sheffield
I know how to read

The after-dark version considered five extra items on the participant self-reported perception of the road lighting (overall satisfaction, brightness, quality, glare and uniformity).

All questions were answered through a six-point rating scale.

4.2.5. Procedure

The field surveys were carried out in November 2016. Every participant was given an information sheet and a consent form to sign before the first session. The participants were taken by the researcher to the test locations in groups. Each group had to experience and rate the environment during daytime and after-dark. The starting sessions were counterbalanced among groups, and four routes were used (Table 7).

Table 7. Pedestrian routes used in the experiment.

	Order in which streets are visited									
Route	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
A1	R6	R4	R8	R10	R7	R3	R9	R2	R5	R1
A2	R1	R5	R2	R9	R3	R7	R10	R8	R4	R6
B1	R8	R4	R6	R10	R5	R1	R2	R9	R3	R7
B2	R7	R3	R9	R2	R1	R5	R10	R6	R4	R8

Table 8 displays the session plan of each group. A total of five groups were formed. There was a group with only 2 participants, used as a pilot group, one group with 4 participants and three groups with 6 participants each.

Table 8. Group session plan for experiment carried out in November 2016.

Group	**Group A***	**Group B**	**Group C**	**Group D**	**Group E**
No. of participants	2	6	4	6	6
Morning session	18th Nov 10:30	22nd Nov 10:30	23rd Nov 10:30	24th Nov 10:30	28th Nov 10:30
Evening session	24th Nov 16:45	25th Nov 16:45	28th Nov 16:45	23rd Nov 16:45	22nd Nov 16:45
First session	Morning	Morning	Morning	Evening	Evening
Route	A1	A2	A1	B1	B2

*Pilot group; number of participants complemented by Group C that was assigned the same route and starting session (in the morning)

Upon arrival to the test locations, each participant was asked to walk alone along a segment of the street, usually between two lamp poles, cross the road and come back to the evaluation point. The participants started the walk at 15 seconds intervals, so they could experience the environment on their own, before assessing it. On the return to the starting point, they were asked to fill in the survey. Each session comprised evaluations in all ten locations, and this task took approximately one hour.

4.3. Results

This analysis focuses on the responses to 8 questions of the questionnaire (Figure 6). Two rating directions were reversed, so higher values represented an enhanced safety perception or a positive assessment of the environment (*I can see a lot of litter and rubbish on this street; I would rather avoid this street if I could*). Results to the question "How risky do you think it would be to walk alone here *at night?*", and the five extra items regarding lighting are examined in chapter 6.

Figure 6. Questions analysed in the present chapter.

Safety questions	*How safe do you think this street is?*	Very dangerous	1	2	3	4	5	6	Very safe
	How anxious do you feel when walking down this street?	Very anxious	1	2	3	4	5	6	Not at all anxious
	_I would rather avoid this street if I could_*	Strongly disagree	1	2	3	4	5	6	Strongly agree
Contextual questions	_I can see a lot of litter and rubbish on this street_ *	Strongly disagree	1	2	3	4	5	6	Strongly agree
	I can see clearly around me	Strongly disagree	1	2	3	4	5	6	Strongly agree
	Apart from the researcher and any other participants, there are lots of other people on the street	Strongly disagree	1	2	3	4	5	6	Strongly agree
	This street is kept in good condition	Strongly disagree	1	2	3	4	5	6	Strongly agree
	How familiar are you with this particular street?	Not at all familiar	1	2	3	4	5	6	Very familiar

*Rating score reversed

Additionally, responses to the bogus question were found to be 99% correct, confirming participant attention when answering. The remaining 1% referred to unexpected individual and cultural aspects, e.g. one test participant stated that in their hometown they would always walk barefoot in the street (however, not during this field study).

Due to the urbanistic differences between the residential roads (R1 to R8) and the park footpath (R9) and the underpass (R10) two analyses are carried out in parallel; N=8, which considered only roads R1 to R8, and N=10, which considered all ten locations. Plotting the 180 measurement points of the three illuminances, these evidenced to be highly correlated *(horizontal vs hemispherical illuminance,* $R^2 = 0.95$*; horizontal vs semi-cylindrical illuminance,* $R^2 = 0.87$*; hemispherical vs semi-cylindrical illuminance,* $R^2 = 0.96$). Due to this high association between metrics, in the present chapter, only horizontal illuminance will be considered further. The stand error of the mean (SEM) for N=180 data points recorded of horizontal illuminance is 1.042, while the standard deviation (SD) is 13.983. While the SEM shows that this data is representative, the SD suggests that there is considerable variance from the expected mean points.

The lighting data for N=10 was not suggested to be normally distributed. Table 10 shows that mean and minimum horizontal illuminance are asymmetrically distributed. It is observable by the central tendency measures that the data is positively skewed, as the mean takes a considerable higher value than the median, and the median a higher value than the mode (Chattamvelli & Shanmugam 2015). Normal distribution presents skewness and kurtosis values approximate to zero (Field, 2009), thus the present lighting data is not normal (horizontal mean skewness = 3.084, kurtosis = 9.639; and horizontal minimum skewness = 3.043, kurtosis = 9.448). Skewness is a measure of symmetry or the distortion of data in a particular direction and kurtosis is a measure of the peakiness of the distribution (Chattamvelli & Shanmugam 2015). Furthermore, a Shapiro-wilks test was performed confirming the data to be significantly asymmetrical ($p < 0.001$).

Table 9. Statistical normality profile of the horizontal mean illuminances for N=10

	Mean
Mean	12.49
Std. Deviation	16.175
Skewness	3.084
Std. Error of Skewness	0.687
Kurtosis	9.639

Std. Error of Kurtosis	1.334
Shapiro-wilks	
Statistic	0.477
Significance	< 0.001

An explanation for this distribution is that R10 presents highly disparate lighting levels (mean horizontal = 58.2, and minimum horizontal = 28.5). Thus, Table 11 reports the results of the same analyses but for N=8, evidencing that if R9 and R10 are not considered the distribution is acceptably normal.

Table 10. Statistical normality profile of the horizontal mean illuminances for N=8

	Mean
Mean	7.380
Std. Deviation	2.111
Skewness	-0.127
Std. Error of Skewness	0.752
Kurtosis	-.338
Std. Error of Kurtosis	1.481
Shapiro-wilks	
Statistic	0.974
Significance	0.930

Table 12 reports the normality analyses for the three after-dark items (safe, anxious and avoid), the day-dark difference of the safety ratings and a composite rating for N=10; and Table 13 reports the same analyses for N=8.

Table 11. Statistical normality profile for three after-dark variables (safe, anxious and avoid), day-dark difference of the safety question and the composite rating of reassurance for N=10

	After-dark			**Day-dark**	**Composite**
	Safe	**Anxious**	**Avoid**		
Mean	3.900	4.125	3.933	0.438	0.515
Std. Deviation	0.499	0.542	0.701	0.484	0.560
Skewness	0.104	0.237	-0.298	0.009	0.125
Std. Error of Skewness	0.687	0.687	0.687	0.687	0.687
Skewness (z-core)	0.151	0.345	-0.434	0.013	0.182
Kurtosis	-0.257	-0.097	0.722	-0.544	-0.553
Std. Error of Kurtosis	1.334	1.334	1.334	1.334	1.334

Kurtosis (z-score)	-0.193	-0.073	0.541	-0.408	-0.415
Shapiro-wilks					
Statistic	0.951	0.961	0.954	0.976	0.972
Significance	0.676	0.792	0.721	0.938	0.906

Considering a group of statistical measures of normality for N=10, the variables seem to present an acceptable normal distribution with skewness and kurtosis values nearing zero. Moreover, the Shapiro-wilks test shows no significance, thus the data can be considered normally distributed.

Table 12. Statistical normality profile for three after-dark variables (safe, anxious and avoid), day-dark difference of the safety question and the composite rating of reassurance for N=8

	After-dark			Day-dark	Composite
	Safe	**Anxious**	**Avoid**		
Mean	3.938	4.141	3.964	0.448	0.540
Std. Deviation	0.556	0.613	0.788	0.362	0.458
Skewness	-0.153	0.125	-0.434	0.511	0.893
Std. Error of Skewness	0.752	0.752	0.752	0.752	0.752
Skewness (z-core)	-0.203	-0.203	0.166	-0.577	0.680
Kurtosis	-0.767	-.847	0.181	-0.292	0.485
Std. Error of Kurtosis	1.481	1.481	1.481	1.481	1.481
Kurtosis (z-score)	-0.518	-0.518	-0.572	0.122	-0.197
Shapiro-wilks					
Statistic	0.939	0.935	0.951	0.961	0.907
Significance	0.601	0.561	0.718	0.815	0.332

The Shapiro-wilks test for N=8 confirms a normal distribution of the reassurance-focused variables. However, skewness and kurtosis statistical values seem to have increased marginally. Thus *z*-scores were calculated for N=10 and N=8, according to the method reported in Field (2009, p.138) and reported in Table 12 and 13, respectively. A *z*-score higher than 1.96 is significant at $p < 0.05$; thus, the dependent variables are normally distributed.

A common approach to stabilise the variance of the data, bringing it to a normal distribution, is to apply a nonlinear transformation to the predictor variable (Chattamvelli & Shanmugam 2015; Chatterjee & Hadi 2012). The best fit for the data is reported in the next section (4.3.1.).

4.3.1. *Is the day-dark approach better than just evaluating after-dark scenes?*

This result section addresses the quality and accuracy provided by the analysis of only after-dark evaluations and day-dark differences. Analysing the reliability of the three items expected to relate to reassurance (*How safe do you think this street is?; How anxious do you feel when walking down this street?; and I would rather avoid this street if I could*) attending to the ratings of each participant in each road after-dark (N=280), these presented an adequate level of internal consistency (Cronbach's alpha of 0.83) (Field 2009).

The affiliation between the dependent variables and the independent variable is best explained by a nonlinear association. The logarithmic transformation was a better fit to the data, converting only the predictor for a linearizable association with the predicted variable, expressed by equation 1 (Chattamvelli & Shanmugam 2015; Chatterjee & Hadi 2012).

Equation 1. Expression of a nonlinear association between the independent variable (X) and dependent variable (Y) using a logarithmic function

$$Y = b0 + b1\, ln(X)$$

The degree association between horizontal illuminances and the after-dark rating for three questions is presented in Table 13. The Pearson correlation was calculated using a two-tailed test. A stronger relationship is verified when the Pearson's R is closer to 1 and it is considered a statistically significant association when the p-value is less than 0.05 (Field 2009).

Table 13. Degree of correlation between illuminance metrics and the mean after-dark ratings for three of the questionnaire items evaluating reassurance.

Question	**Correlation with horizontal illuminance**					
	Mean		**Minimum**		**Uniformity**	
	R	***p***	**R**	***p***	**R**	***p***
N=10 roads						
Safe	0.14	0.699	0.49	0.155	0.83	0.003
Anxious	0.16	0.662	0.49	0.155	0.80	0.005
Avoid	0.08	0.829	0.41	0.236	0.76	0.011
N=8 roads						
Safe	0.51	0.202	0.86	0.006	0.95	<0.001
Anxious	0.42	0.295	0.81	0.015	0.93	0.001
Avoid	0.54	0.172	0.89	0.003	0.98	<0.001

Safe: How safe do you think this street is?
Anxious: How anxious do you feel when walking down this street?

Avoid: I would rather avoid this street if I could

Thus, the data suggest that the relationship between the variables after-dark ratings and horizontal mean illuminance is not significant. However, there is a significant correlation between these appraisals and minimum horizontal illuminance and uniformity; moreover, this relationship seems to be stronger with uniformity illuminance. Moreover, excluding the test locations that are significantly different in landscape terms to residential roads (open space or enclosed space) influences the significance of the association with minimum horizontal illuminance. The ratings to the three survey items show a high association degree for both N=10 (*safety vs anxious* $R^2 = 0.90$; *safe vs avoid* $R^2 = 0.92$; *anxious vs avoid* $R^2 = 0.88$) and N=8 (*safety vs anxious* $R^2 = 0.87$; *safe vs avoid* $R^2 = 0.88$; *anxious vs avoid* $R^2 = 0.80$). Consequently, Figure 7 to 9 only demonstrate the graphical representation of safety after-dark appraisals and horizontal minimum, mean, and uniformity.

Figure 7. Safety after-dark ratings plotted against mean horizontal illuminances for N=10 and N=8.

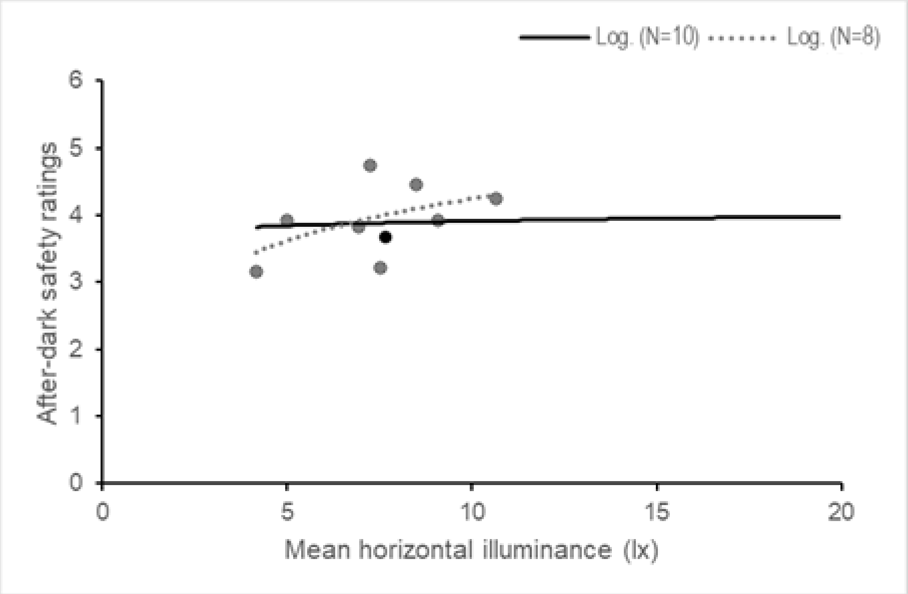


Figure 8. Safety after-dark ratings plotted against minimum horizontal illuminances for N=10 and N=8.

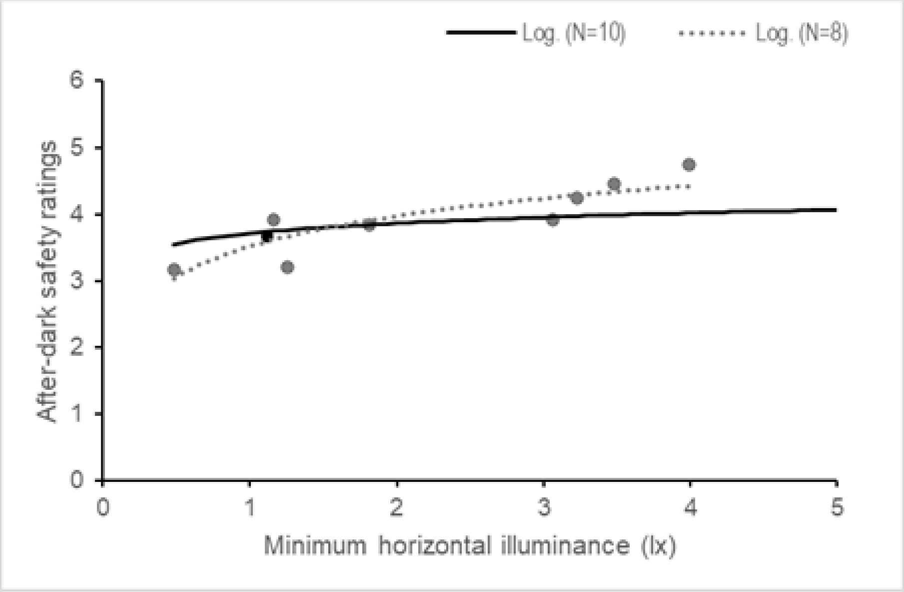
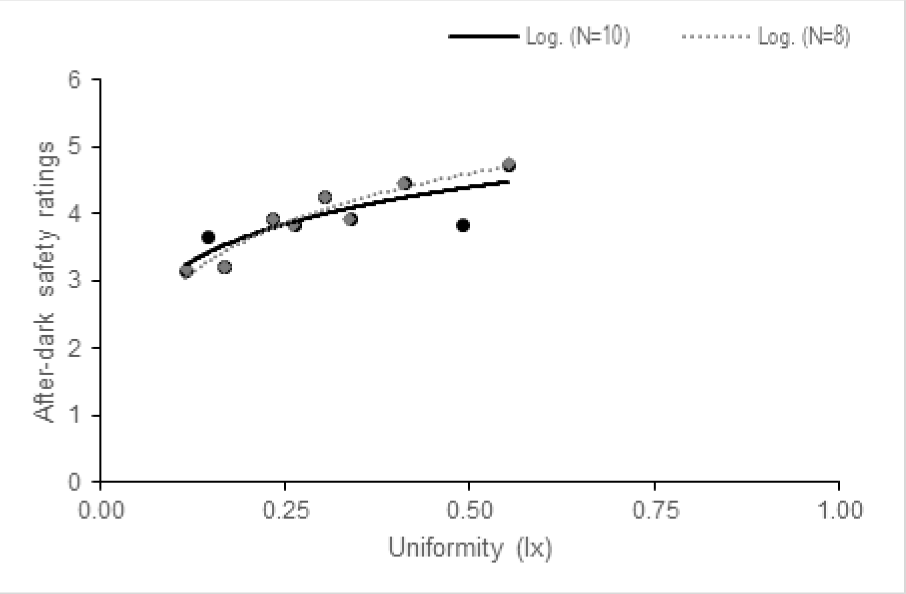


Figure 9. Safety after-dark ratings plotted against horizontal illuminance uniformities for N=10 and N=8.



Although, the association between these evaluations and the lighting levels are statistically significant, graphical representation of the after-dark ratings displays a potential range bias. This means that the highest lighting level in the range of test locations, rated as the safest. Range bias should be acknowledged as it might influence the prospect to draw conclusions on the optimal illuminance value or an overall threshold. Therefore, the day-dark approach (Boyce et al. 2000) was also applied in this study. It is important to note that data collection using surveys is unable to produce absolute values (section 3.1.4) due to the implicit subjectivity and that while this approach could help reduce stimulus range bias because it establishes a daytime baseline for comparison with the after-dark ratings, it does not account for all the conditions experienced in-between test locations.

The difference between daytime and after-dark ratings to each question for each location of the same participant were calculated. These were then averaged per location. The averaged day-dark scores of the safety variable (*How safe do you think this street is?*) are presented in Table 14. This question was selected as it is used not only by Boyce et al (2000) but it is also one of the standard questionnaire items in reassurance studies. The logarithmic function explains the association better than the linear function.

Table 14. Goodness of fit of logarithmic function to explain day-dark difference of safety ratings plotted against mean, minimum and uniformity of horizontal illuminance.

Illuminance measure	**N=10 roads**		**N=8 roads**	
	R^2	**p-value**	**R^2**	**p-value**
Mean	0.61	0.008	0.81	0.002
Minimum	0.83	0.001	0.84	0.001
Uniformity	0.70	0.002	0.62	0.02

Minimum illuminance and uniformity have a stronger correlation to the day-dark difference than mean horizontal illuminance when considering all ten locations (N=10). However, if only the eight residential roads are considered (N=8), mean and minimum horizontal illuminances are not only stronger associated as these relationships between variables are more significant (R^2= 0.81, *p*=0.002; R^2= 0.84, *p*=0.001). Minimum horizontal illuminance always shows a better relationship to day-dark differences, whereas for the ten locations uniformity displays a stronger association, and for the eight locations mean illuminance is better than uniformity. This confirms that the type of location is relevant for the established relationship between lighting and reassurance. However, minimum and uniformity display a steadier relationship, with lesser variance in the level of association, separate from changes to the location sample.

Figure 10 to 12 show the day-dark differences plotted against the mean, minimum and uniformity of horizontal illuminance, respectively, for N=10 and N=8.

Figure 10. Safety day-dark differences plotted against horizontal illuminance mean for N=10 and N=8

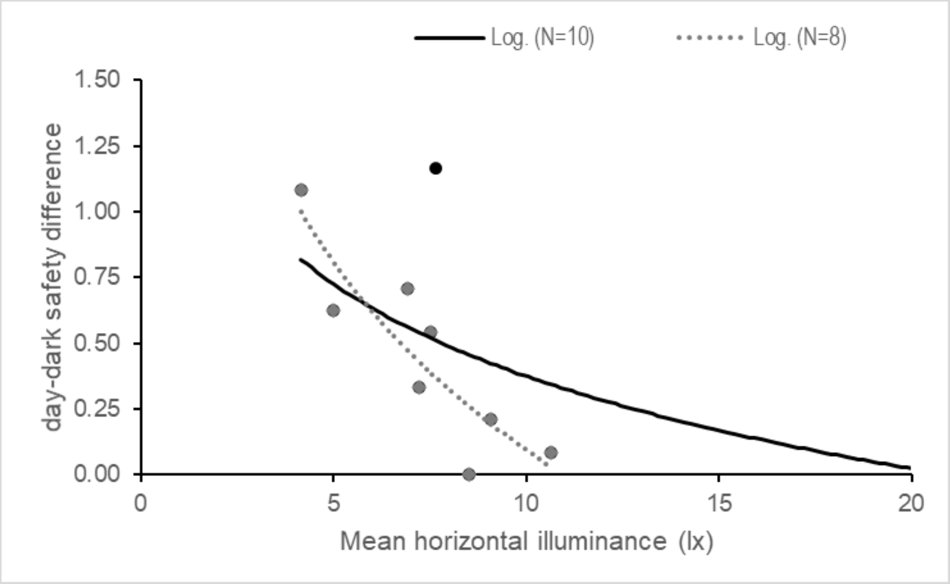


Figure 11. Safety day-dark differences plotted against horizontal illuminance minimum for N=10 and N=8

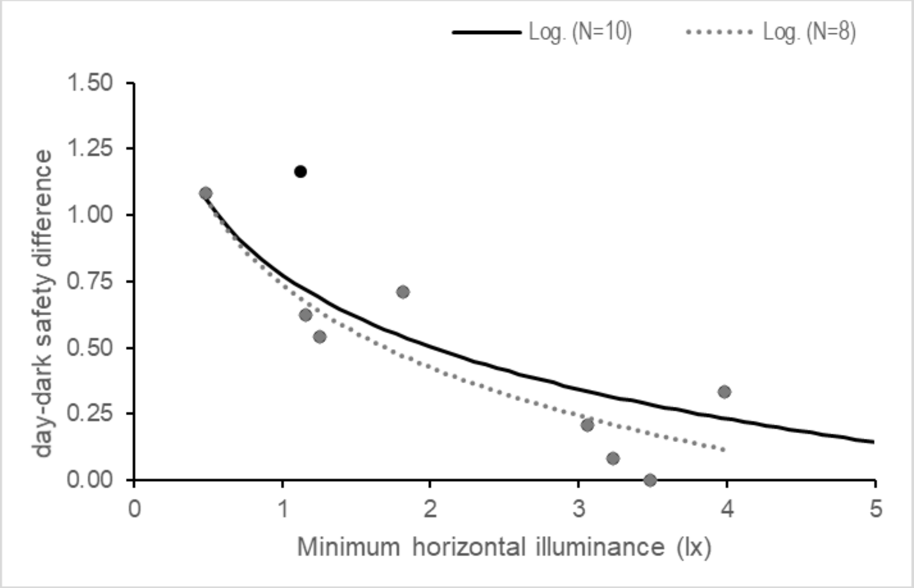
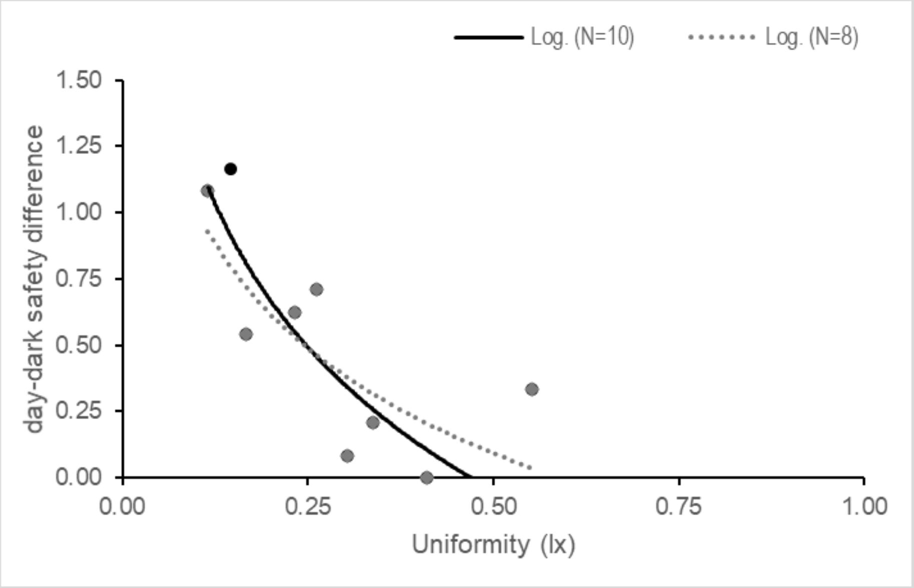


Figure 12. Safety day-dark differences plotted against horizontal illuminance uniformities for N=10 and N=8



4.3.2. *Are single items enough in portraying the fear of crime-reassurance feelings?*

Although the questionnaire can only measure perceptions (cognitive level), it was designed to register self-reported behaviours and emotional responses to the environment. A Principal Component Analysis (PCA) was applied to the day-dark rating differences database of eight questions (N=240; which signifies the day-dark differences of the ratings of 24 participants in 10 locations). The bogus question and the item on the risk felt at the location at night were excluded from the analysis. This statistical analysis has been used in other built-environment and perceived safety studies (Aditjandra, Mulley & Nelson 2013; Lindelöw et al. 2017; Vauclair & Bratanova 2017).

Kaiser-Meyer-Olkin (KMO) test assesses the appropriateness of using factor analysis on data (Hutcheson & Sofroniou 1999; Barkus, Yavorsky & Foster 2006; Field 2009). In the case of our database, the result of sample adequacy of the KMO test is 0.730. Values between .70-.79 mean that the sample is acceptable (Hutcheson & Sofroniou 1999; Field 2009); below this threshold would be considered mediocre, while above it would be considered excellent.

The principal component analysis identifies patterns in data by clustering variables. For the Principal Components analysis, no rotation solution was selected, and the Eigenvalue was set to greater than 1. While the rotation defines the type of relationship expected to occur between variables, facilitating understanding of the extracted components by minimizing the variable loadings into several components, the Eigenvalue indicates the relative importance of the direction in which data is dispersed (Field 2009). Since the PCA carried out was intended to extract a single component that represented reassurance, rotation of components was not required.

The component scores were produced through the *regression method* function in *SPSS IBM Statistics*. The PCA grouped and weighted the survey items into components that represent different underlying dimensions of the data. From this analysis, two components were extracted. Component loadings that were >0.4 are more significant for each construct.

The first component, named Reassurance, loaded *street avoidance* (0.801), *to feel safe* (0.783), *to feel anxious* (0.761), *to see clearly* (0.584) and *good condition of the street* (0.450). The second component included the items *litter* (0.780), *good condition of the street* (0.530), *the presence of lots of people* (-0.490) and *familiarity with the street* (-0.423), thus being labelled as Contextual. However, the present work is only considering the *Reassurance* dimension which was the first component extracted and presented below (Table 15).

Table 15. Component Matrix extracted using Principal Component Analysis and component scores (Fotios, Monteiro & Uttley, 2019).

Survey question	Component loading	Component score
I would rather avoid this street if I could	0.801	0.327
How safe do you think this street is?	0.783	0.319
How anxious do you feel when walking down this street?	0.761	0.310
I can see clearly around me	0.584	0.238
This street is kept in good condition	0.450	0.184
How familiar are you with this particular street?	0.207	0.084
Apart from the researcher and any other participants, there are lots of other people on the street	0.171	0.070
I can see a lot of litter and rubbish on this street	0.041	0.017

Using the component scores, a composite rating of reassurance that considered all survey items was calculated. This was done by resorting to the component scores to weight each item rating of each participant in each location (p. 633 in Field 2009) as shown in Equation 2 below.

Equation 2. Weighting of each survey item into a composite rating of Reassurance

$$Reassurance = (avoid\ street\ rating * avoid\ street\ score) \\ + (safety\ rating * safety\ score) + (anxious\ rating * anxious\ score) \ldots$$

After, these were averaged per test location. Ratings to all eight survey items were considered, however the items that were less relevant to reassurance (loading <0.4), also weight less into the composite rating.

The minimum and maximum composite score is ±7.74, hence the scores were transformed to match the day-dark difference range of the original data (±5). This was done by applying equation 3 to every score in an Excel spreadsheet.

Equation 3. Equation used for standardisation of the composite ratings ±7.74 scale into the day-dark difference scale of ±5

$$f(\chi) = \frac{(b-a)*(x-\min)}{\max - \min} + a$$

Table 16 shows the mean composite score and the transformed composite score and respective standard deviation per road.

Table 16. Mean composite day-dark difference scores and transformed composite score (Fotios, Monteiro & Uttley, 2019).

Location	Composite score		Transformed composite score	
	Mean	Std dev	Mean	Std dev
Road 1	0.96	1.09	0.62	0.70
Road 2	2.11	1.15	1.36	0.74
Road 3	0.60	0.98	0.39	0.63
Road 4	0.33	1.08	0.21	0.70
Road 5	0.21	0.96	0.14	0.62
Road 6	0.15	0.96	0.10	0.62
Road 7	1.22	1.00	0.78	0.65
Road 8	1.18	1.19	0.76	0.77
Road 9	1.84	1.37	1.19	0.88
Road 10	-0.57	1.22	-0.37	0.79

A road with a lower score indicates a smaller day-dark difference in reassurance evaluations, which suggests a better effect of road lighting. The negative score (R10) suggests that participants felt more reassured after-dark than in daytime in that location; thus, a positive score means the opposite. Figure 13 to 15 show the reassurance composite rating plotted against horizontal illuminance mean, minimum and uniformity using a logarithmic function, as this was the best fit for the data. Table 17 shows the level of association between the transformed composite rating and horizontal mean, minimum and uniformity. This was done by applying a logarithmic function to N=8 and N=10. Both analyses show that there is a stronger relationship between reassurance and minimum and uniformity.

Table 17. Goodness of fit of logarithmic function to explain composite day-dark difference plotted against mean, minimum and uniformity of horizontal illuminance (Fotios, Monteiro & Uttley, 2019).

Illuminance measure	**N=10 roads**		**N=8 roads**	
	R^2	**p-value**	**R^2**	**p-value**
Mean	0.56	0.013	0.65	0.016
Minimum	0.86	<0.001	0.92	<0.001
Uniformity	0.85	<0.001	0.83	0.002

Figure 13. Reassurance composite rating plotted against mean horizontal illuminance for N=10 a

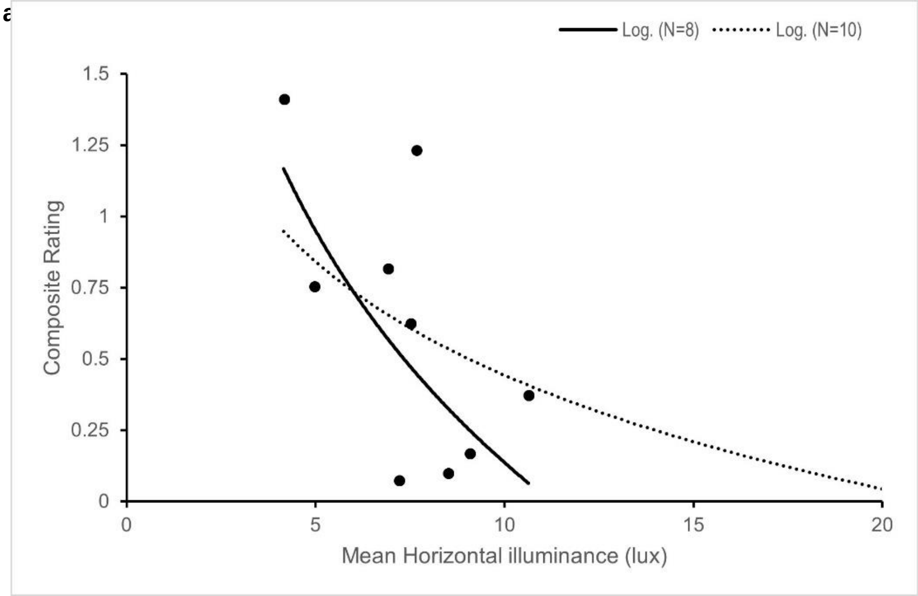


Figure 14. Reassurance composite rating plotted against minimum horizontal illuminance for N=10 and N=8.

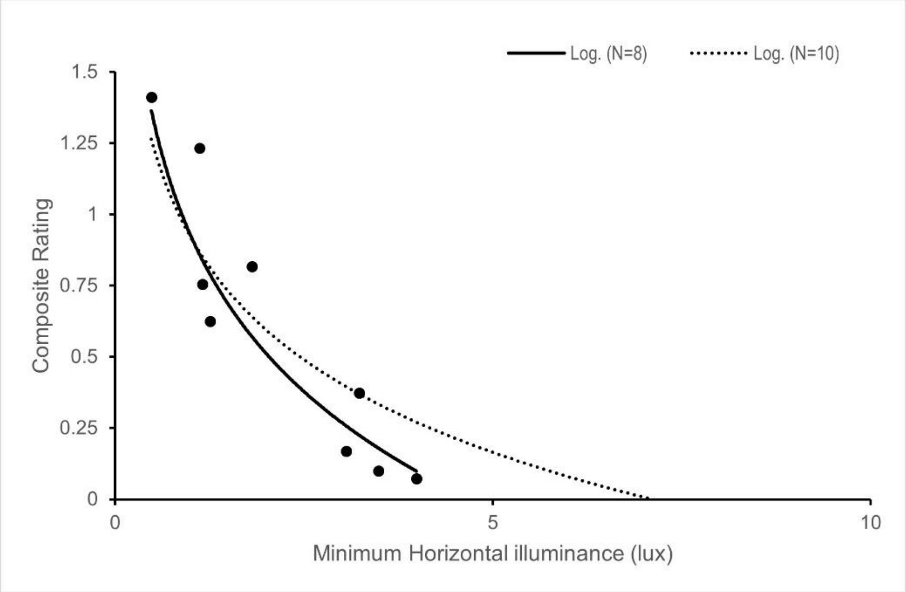
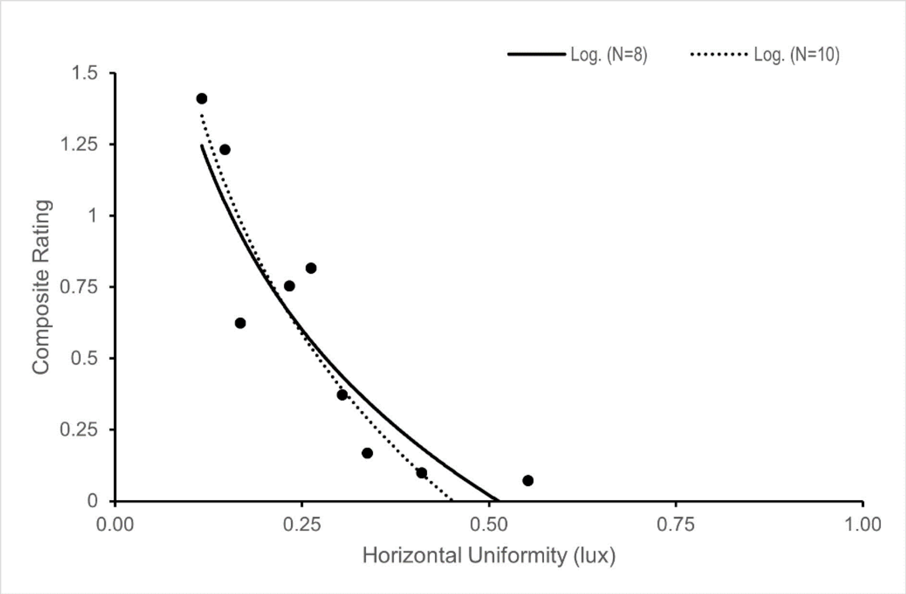


Figure 15. Reassurance composite rating plotted against horizontal uniformity for N=10 and N=8.



4.3.3. *Is there an optimum level of illuminance for reassurance?*

Previous analyses (in sections 4.3.1. and 4.3.2) showed that horizontal uniformity and minimum illuminance have a stronger association with both the safety question and the reassurance composite rating than the horizontal mean illuminance.

Following these results, a regression modelling was applied to examine if reassurance can be sufficiently predicted by only considering one measurement or if it is best predicted by a combination of metrics. The multiple regression models were done by considering the logarithmic values of the mean, minimum and uniformity of horizontal illuminance through a forced entry method of these predictors. This was done considering N=10 (Table 18) and N=8 (Table 19). The Akaike Information Criterion (AIC) was also examined as a measure of goodness of fit of the model. The Akaike Information Criterion (AIC) is a mathematical method used for model comparison and determination of the best fit. The AIC indicates the quality of estimation of the dependent variable by the predictors used, attending to the simplicity of the model (Akaike 1974).

The best model is that offering a higher R-squared and lower AIC values. Table 18 demonstrates that a combination of two predictors (Mean and Minimum; Mean and Uniformity; or Minimum and Uniformity) fit best the data. Nevertheless, the model R^2 and *p*-value offer no significant improvement if only minimum horizontal illuminance is considered. Table 19 evidences that a model using minimum horizontal illuminance only as a single predictor offers the highest prediction power. Furthermore, using more than two predictors shows no increase in prediction capacity over the use of only two predictors (N=10) and minimum horizontal illuminance (N=8).

Table 18. Results from multiple regression models using combinations of mean, minimum and uniformity of horizontal illuminance to predict the transformed composite day-dark difference score of reassurance (N=10) (Fotios, Monteiro & Uttley, 2019).

Illuminance measure used as predictor	Constant	Beta value	Individual predictor p-value	Model R^2 *	Overall model p-value	AIC
Mean	1.77	-0.57	0.016	0.54	0.016	14.00
Minimum	0.92	-0.47	<0.001	0.84	<0.001	3.13
Uniformity	-0.79	-0.99	<0.001	0.85	<0.001	2.82
Mean + Minimum	0.02	0.54 -0.79	0.036 <0.001	0.90	<0.001	-1.56
Mean + Uniformity	0.01	-0.25 -0.80	0.041 <0.001	0.90	<0.001	-1.53
Minimum + Uniformity	0.01	-0.25 -0.55	0.041 0.037	0.90	<0.001	-1.54
Mean + Minimum + Uniformity	0.04	4.02 -4.27 3.50	0.829 0.819 0.852	0.88	0.001	0.37

* Multiple R-squared for models with only one predictor. Adjusted R-squared when more than one predictor included in model.

Table 19. Results from multiple regression models using combinations of mean, minimum and uniformity of horizontal illuminance to predict the transformed composite day-dark difference score of reassurance (N=8) (Fotios, Monteiro & Uttley, 2019).

Illuminance measure used as predictor	Constant	Beta value	Individual predictor p-value	Model R^2 *	Overall model p-value	AIC
Mean	2.87	-1.19	0.018	0.63	0.018	7.12
Minimum	0.93	-0.60	<0.001	0.91	<0.001	-4.00
Uniformity	-0.56	-0.84	0.002	0.82	0.002	1.37
Mean + Minimum	0.83	0.05 -0.62	0.891 0.012	0.87	0.003	-2.03
Mean + Uniformity	0.84	-0.57 -0.62	0.077 0.011	0.87	0.002	-2.12
Minimum + Uniformity	0.82	-0.56 -0.06	0.079 0.879	0.87	0.002	-2.04
Mean + Minimum + Uniformity	1.11	-17.0 16.2 -16.9	0.456 0.470 0.454	0.86	0.011	-1.30

* Multiple R-squared for models with only one predictor. Adjusted R-squared when more than one predictor included in model.

The modelling examination suggest that minimum illuminance is the best predictor of reassurance. Although for N=10 adding a second term to the model seems to improve the prediction power, this change could be related to the urbanistic distinctive characteristics of R9 and R10, which are a pathway in a park and an enclosed underpass (Appleton 1975; Boomsma & Steg 2014). Thus, the resultant models for N=10 and N=8 are presented in the equations 3 and 4.

Equation 4. Predictive model using horizontal minimum illuminance for N=10.

$$Composite\ day - dark\ difference\ =\ 0.92 - 0.47\ ln(Emin)$$

Equation 5. Predictive model using horizontal minimum illuminance for N=8.

$$Composite\ day - dark\ difference\ =\ 0.93 - 0.60\ ln(Emin)$$

Following the premise that effective lighting is one that decreases the difference between daytime and after-dark assessment of an environment. Table 20 shows a prediction of illuminances for such a reduction at 0.5 and 1.0 units, considering the single safety day-dark difference or the reassurance composite.

Table 20. Horizontal illuminances estimated according to day-dark differences of either 1.0 or 0.5 units (Fotios, Monteiro & Uttley, 2019).

Evaluation	**Data sample**	**Mean illuminance (lux)**		**Minimum illuminance (lux)**		**Uniformity**	
		0.5	**1.0**	**0.5**	**1.0**	**0.5**	**1.0**
Safety question	N=10; All ten locations	8.4	3.2	2.2	0.6	0.26	0.13
	N=8; Underpass and park excluded	7.1	4.3	1.9	0.6	0.27	0.11
Composite response	N=10; All ten locations	9.1	3.7	2.5	0.8	0.27	0.16
	N=8; Underpass and park excluded	7.4	4.7	2.1	0.9	0.29	0.15

Horizontal uniformity and minimum, which in previous analyses showed a higher effect on the reported reassurance, display relatively similar results (section 4.3.1. and 4.3.2). Higher variation in mean illuminance is observable between N=10 and N=8. Including the test locations R9 and R10 in the estimations increases the illuminance mean needed for a reduction from 1.0 to a 0.5 day-dark difference. This suggests that the park pathway and the underpass require a higher level of mean illuminance to decrease the day-dark difference.

According to these estimations, for a decrease of the day-dark difference to 0.5 units, on a six-point rating scale, road lighting should provide a mean horizontal illuminance of 7.0 to 9.0 lux, a minimum of approximately 2.0 lux, or a uniformity of approximately 0.25.

4.4. Discussion

The first field study was carried out to explore the potential effect of lighting levels on pedestrian reassurance. Horizontal mean, minimum and uniformity were considered. This was done by examining four propositions (section 4.1.) related to the level of association between mean horizontal illuminance and (1) appraisals done only after-dark or (2) the safety item day-dark difference, (3) the level of association with horizontal minimum illuminance and uniformity, and (4) the benefit of using a composite rating that accounts for multiple reassurance-related items.

The level of association of after-dark ratings to three questions was examined (*How safe do you think this street is?; How anxious do you feel when walking down this street?; and I would rather avoid this street if I could*). Although there is a certain degree of association with lighting levels, particularly with minimum horizontal illuminance and horizontal uniformity, the graphical representation illustrates a provided illuminance range bias. Reassurance scores increase as illuminance levels do. This confirms the hypothesis that focusing on after-dark ratings is unlikely meaningful for drafting a threshold of illuminance. As the provided illuminance ranges are likely to fluctuate in each study, defining that the highest illuminance is the best has little benefit. In a real-life scenario, there are other practical elements of importance for determining road lighting, such as energy waste or financial investment.

Furthermore, minimum horizontal illuminance and horizontal uniformity for N=8 exhibited a significant correlation while for N=10 only uniformity correlated significantly in all three items. The locations R9 and R10 were an open and an enclosed space, respectively. These results seem to reinforce the principle that diverse landscapes should be investigated distinctly, due to the different signals emitted. Locations R9 and R10 are designed in a manner that challenge the assessment of potential threats or difficulty the escape, which are aspects said by Appleton (1975) to potentially induce anxiety in individuals. While residential roads might have vegetation or building design elements that could, for example, facilitate hiding spots, these elements are unlikely to be as extreme as in an underpass (R10) or a park (R9).

Another important methodological consideration is that the three items tapped into a perceptual, emotional and behavioural component of reassurance, respectively. This is relevant, as these items score and seem to associate differently with the metrical levels of road lighting. For example, the behavioural item correlates lower than the cognitive and emotional items with lighting levels. This might be because perceiving or displaying an emotional reaction to an environment does not necessarily enforce a behavioural response of avoidance; other behavioural responses might take place or none (Maxfield 1984; Rader, May & Goodrum 2007). Following that the usage of a single measurement item is frequent, this highlights the deficiency of such method. Focusing on a sole item to measure reassurance or fear of crime obscures other potential elements to this multi-dimensional concept. Thus, measuring reassurance based on a perceptual, emotional or behavioural aspect will likely produce different, and not necessarily comparable, results.

Anticipating the premise that after-dark results would be range biased, a day-dark approach was applied as executed by Boyce et al (2000). Thus, evaluations in daytime and after dark were collected and the differential calculated. This was done for the safety item only. The day-dark difference was significantly associated with mean horizontal illuminance (R^2=0.61, p=0.008 for N=10; R^2=0.81, p=0.002 for N=8), however best predicted by minimum horizontal for both N=10 and N=8 (R^2=0.83, p=0.001; R^2=0.84, p=0.001, respectively). Interestingly, uniformity showed higher association level with the day-dark difference when the park pathway and the underpass (R9 and R10) were included ($R^2=0.70$, $p=0.002$), but its association degree was less relevant when only residential roads were considered ($R^2=0.62$, $p=0.02$). Some studies (Narendran, Freyssinier & Zhu 2016; Bullough, Snyder & Kiefer 2019; Bhavagavathula & Gibbons 2020) have identified uniformity to be a relevant metric in determining the level of safety felt, however in car parks rather than pedestrian footpaths. Thus, if the alleged implications of the landscape design are to be credited, as the present results seem to recommend, the importance of uniformity for residential roads is to be determined.

Following the premise that reassurance should be measured as a multi-dimensional construct (section 3.1), a principal component analysis was performed to weight the questionnaire items into a single composite rating. The questionnaire was designed considering the existing literature and previously posed items. However, instead of assuming that results on the perceived level of safety would represent the emotional and behavioural component or the contextual implications, this study proposes calculating a score that accounts for these key elements. The extension of the questionnaire is a recognised limitation. The level of reassurance that someone reports is potentially affected by other factors as for example self-efficacy perceptions or previous victimisation (Killias 1990; Adams & Serpe 2000; Rader, Cossman & Porter 2012). Nevertheless, as an exploratory measuring instrument used in sessions that lasted between 1-2 hours, a compromise had to be made.

The principal component analysis identified a reassurance-related component, in which the expected survey items presented the highest weights. Following the weighting of these and the calculus and standardization of the composite rating, the association with horizontal mean, minimum and uniformity was established for all ten roads evaluated (N=10) and also the subset of eight roads (N=8) with the park path and underpass omitted. These results showed that for both conditions (N=10 and N=8) horizontal minimum and uniformity were best predictor terms.

Current standards for subsidiary roads (BS EN 13201-2:2015) define six lighting classes, to which several lighting levels are designated. However, horizontal uniformity is not specifically stated, but instead assumed by the mean and minimum guidelines. This could be because uniformity does not account for the absolute level of light emitted, which is an essential factor for a sustainable energy use. Although results from this field study are not conclusive with regards to the importance of uniformity, due to the small location sample and the size effect of the sample, these seem to suggest that stipulating the horizontal minimum and uniformity are potentially more useful to determine than the horizontal mean. In safety terms, good lighting is one that reduces the difference in reassurance felt in daytime and after-dark in locations. Thus, a reduction to day-dark difference of 0.5 units in a 6-point rating scale suggests adequate lighting.

Estimations resulting from this chapter analyses suggest that a day-dark difference of 0.5 units is achieved at a horizontal minimum of 2.0 lux, a mean horizontal illuminance of 7.0 to 9.0 lux, or a uniformity of approximately 0.25. Considering that a day-dark difference of 0.5 units means that after-dark evaluations of reassurance are slightly below that experienced in daytime, this could be considered adequate lighting. These lighting conditions fall into the P3 (mean = 7.5 lux, min = 1.5 lux) and P2 (mean = 10 lux, min = 2.0 lux) lighting classes (CIE 115, 2010). The uniformity is 0.2 in all classes (CIE115:2010). These are the classes previously labelled for heavy to moderate pedestrian or cycling usage. However, when roads are considered to have minor night-time use by pedal cyclists or pedestrians, namely associated with residential usage, these fall into the P5 (mean = 3.0, minimum = 0.6 lux) and P4 (mean = 5.0 lux, minimum = 1.0 lux) (CIE 115, 2010). Estimations resulting from this dataset point out that such conditions (mean horizontal illuminance of 3.0 to 5.0 lux, a minimum of 0.6 to 0.9 lux, or a uniformity of approximately 0.15) would translate into a day-dark difference of 1 unit.

Additionally, these results suggest that for residential roads (N=8) the optimal threshold for horizontal mean illuminance is slightly below the one of 10-lux suggested in safety studies in other environments (Narendran, Freyssinier & Zhu 2016; Bullough, Snyder & Kiefer 2019; Bhavagavathula & Gibbons, 2020). Therefore, further investigation of the prediction power of uniformity and the suggested threshold for the other metrics is required.

4.5. Summary

The complexity of signals emitted by the urban tissue requires road lighting effects to be isolated from other signals. Recording the level of reassurance in daytime and after-dark allows to determine the difference between both conditions. Thus, it provides a better understanding of the road lighting effect in reassurance after-dark.

Having considered different approaches to data analysis, results show that the day-dark approach suggested by Boyce et al (2000) reported better results with regard to the examination of the relationship of lighting levels and reassurance in pedestrians. Using only after-dark evaluations of locations demonstrates a range bias, where the highest mean, minimum and uniformity seem to be perceived as safer. While considering the difference between appraisal in daytime and after-dark conditions, seems to successfully isolate the overall feeling of reassurance in the location. This method assumes that lighting can only make someone feel as safe in a certain location after-dark as in daytime.

In this chapter, another consideration given to previous methodology comprised the usage of a single item versus multiple items to measure reassurance. Following the analysis on the after-dark only appraisals slight variance in responses to cognitive, emotional, and behavioural survey items is identifiable. Having weighted numerous items into a composite rating, resorting to principal component analysis, the association with lighting levels seem statistically of a higher significance than when only after-dark or a single day-dark difference is to be considered.

Furthermore, if results from the three approaches are considered, uniformity and minimum horizontal seem to predict reassurance levels better than mean horizontal illuminance. Regression modelling results show that there is little benefit in using more than one metric to predict levels of reassurance. Following these data results, for a decrease of the day-dark difference to 0.5 units, road lighting should provide a mean horizontal illuminance of 7.0 to 9.0 lux, a minimum of approximately 2.0 lux, or a uniformity of approximately 0.25.

These results are to be confirmed in chapter 5, in the result analysis from a replication and expansion of this field study.

Chapter 5. Field study 2: Is uniformity better than horizontal mean illuminance for reassurance prediction?

5.1. Introduction

The key finding from chapter 4 is that minimum horizontal illuminance and minimum to mean illuminance uniformity seem to predict better the effect of lighting on pedestrian reassurance. The study focused on exploring methodological issues: considering only after dark evaluations, using a single item to investigate reassurance and, finally, the relationship between accurate lighting levels (horizontal illuminance mean, minimum and uniformity) with self-reported reassurance. The sample used in field study 1 entailed twenty-four participants who evaluated only eight residential roads. This means that locations were not targeted for their lighting spatial distribution. Thus, to investigate further the previous results on horizontal illuminance minimum and uniformity as metrics that are better associated with a road perceived as being safe and at which levels the day-dark difference is reduced, a replication and amplification of that study was carried out. This second field study again used the day-dark approach (Boyce et al. 2000) and expanded the previous study by using a larger participant sample (increased from 24 to 35) and a greater number of test locations (increased from 10 to 16). The test locations were selected to provide a variation in horizontal illuminance and uniformity as established from measurement of horizontal illuminances and uniformities prior to location sample selection.

The field study 2 explores three premises:

1. Uniformity and minimum are better reassurance predictors than horizontal illuminance.
2. Other metrics such as hemispherical and semi-cylindrical illuminances are good predictors of reassurance.
3. Metric thresholds found in field study 1 are validated by estimations in field study 2.

5.2. Method

Field study 2 sought to confirm the hypothesis that higher uniformity is associated with higher reassurance in pedestrians. This was done by using the same method as field study 1 but with careful choice of extra evaluation locations. Seven locations from the field study 1 were retained, and nine new roads were added to the evaluation pool, resulting in a total of 16 test locations.

Light measurements were then carried out in these locations as described in section 4.2.2. Participants evaluated these 16 residential roads, in Sheffield, in daytime and after-dark. There was a minor change to the questionnaire design. An additional item was included to both after-dark and daytime versions ("How risky do you think it would be to walk here?"). Field study 1 used a similar item, however, it included the phrasing "at night". Both items were included to investigate the importance of phrasing and the potential impacts of requiring participants to assess and imagined or recalled location after-dark. Those results are examined in chapter 6.

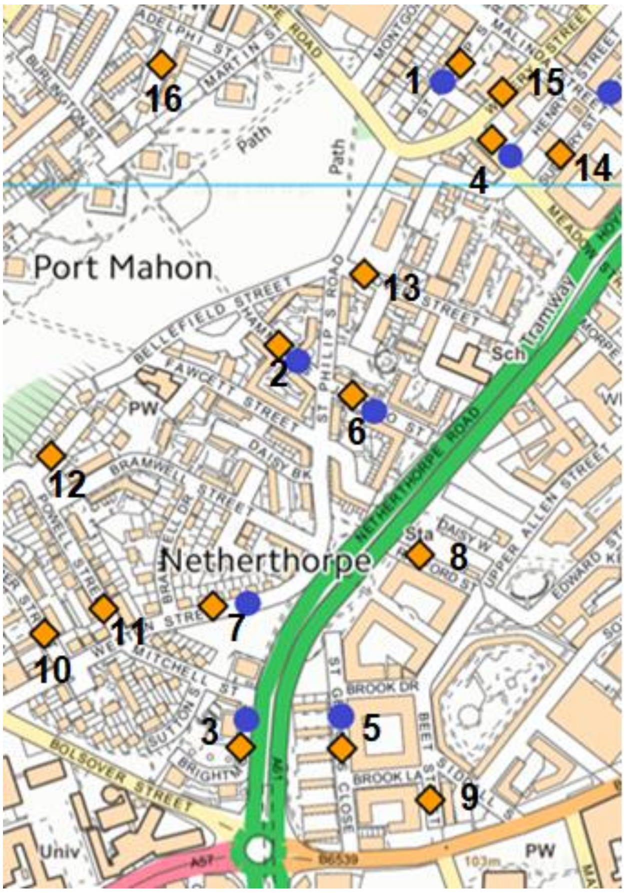
5.2.1. Test locations

From the original 10 locations used in field study 1, only residential roads were considered, thus excluding the underpass and park pathway. Due to highway maintenance works being carried out during the time of field study 2, the original R1 had to be excluded. Consequently, seven original locations were maintained (labelled in chapter 4: R2 to R8; but labelled R1 to R7 in chapter 5). Previous studies (Davidson & Goodey 1991; Painter 1996; Painter & Farrington 1999) compared before and after relighting of an area crime and fear of crime data (section 3.4). There were a number of inconsistencies in these studies, namely the lack of lighting levels reporting. Between field study 1 and 2, the neighbourhood studied suffered a relighting. Thus, residential roads from field study 1 were used in field study 2 to examine if observable differences due to different lighting levels in the same environment were verified.

Preliminary measurements of horizontal illuminance were undertaken in a pool of 23 roads, resulting in the selection of 9 roads. The criteria to choose from this pool were (1) the range of horizontal illuminances and uniformities and (2) the walking distance among locations, thus only considering locations in the *Netherthorpe* neighbourhood. The preliminary lighting measurements for this pool of 23 roads and respective estimations of horizontal mean and uniformity for each location are shown in Appendix E. The estimation for the segment was done by applying the proposed method by Yao et al (2018), resorting to three measurement points in each side of the road (below lamp, a quarter distance, and half distance between lamp poles). Locations labelled R1 to R9 refer to field study 2 locations R8 to R16, respectively

(Table 21; Appendix G). Figure 16 shows a map of the 16 test locations of this study and the 8 residential roads from the previous study.

Figure 16. Map of previous and present study test locations identified with blue and orange symbols respectively (N=16).



The coordinates and lighting levels of all 16 locations are presented in Table 21. During the time interval between field study 1 and field study 2, a relighting intervention in this residential area was carried out by the local authority. Existing light sources were replaced with LED arrays, some lamp post locations and lighting levels changed. Across the 16 test locations, the lamp post arrangement in most was single-sided: in roads R6 and R15 the lamp posts were staggered (Table 21). In R2 and R13 some buildings had lighting on their façades which contributed to the measured values.

Table 21. Mean, minimum (min) and uniformity (U) of horizontal, hemispherical and semi-cylindrical illuminances measurement values of the 16 test locations. All locations were residential roads and the light source was LED.

Road	Coordinates of observation location	Lighting configuration	Pole spacing (m)	Number of data points per side	Distance walked by observers (m)	Horizontal illuminance (lux)			Hemispherical illuminance (lux)		Semi-cylindrical illuminance (lux)	
						mean	min	U	mean	min	mean	min
R1	53°23'19.0"N 1°28'53.3"W	Single sided	43.5	15	88.8	3.90	0.15	0.039	3.15	0.33	2.78	1.06
R2	53°23'10.4"N 1°29'00.8"W	Single sided	25.2	10	56.0	9.29	4.09	0.440	6.41	3.61	4.59	1.17
R3	53°22'58.1"N 1°29'04.2"W	Single sided	36.6	15	97.2	10.02	3.41	0.340	7.39	3.16	5.90	3.39
R4	53°23'17.5"N 1°28'51.8"W	Single sided	38.4	15	100.0	11.09	1.02	0.092	7.94	1.30	4.29	0.64
R5	53°22'57.8"N 1°28'59.0"W	Single sided	26.9	10	59.1	4.78	1.10	0.230	6.15	1.21	3.29	1.38
R6	53°23'09.4"N 1°28'59.3"W	Staggered	25.3	10	90.4	7.76	1.90	0.245	4.69	1.74	3.12	1.23
R7	53°23'02.7"N 1°29'07.3"W	Single sided	49.1	17	176.8	1.16	0.36	0.306	1.13	0.52	0.97	0.26
R8	53°23'04.4"N 1°28'55.2"W	Single sided	23.9	10	77.7	7.81	2.20	0.282	7.53	2.53	6.29	2.78
R9	53°22'57.3"N 1°28'54.5"W	Single sided	21.8	10	76.6	8.65	5.67	0.656	5.76	2.60	4.30	2.09
R10	53°23'01.3"N 1°29'13.4"W	Single sided	28.4	10	59.8	7.43	2.14	0.288	5.07	2.35	3.23	0.65
R11	53°23'02.2"N 1°29'10.5"W	Single sided	28.2	10	60.0	6.39	0.86	0.134	4.33	0.80	2.30	0.75
R12	53°23'06.9"N 1°29'14.6"W	Single sided	28.7	10	64.2	7.41	2.13	0.288	5.31	2.33	3.37	0.58
R13	53°23'13.4"N 1°28'58.7"W	Single sided	35.6	15	79.6	8.60	0.85	0.099	6.16	1.73	3.56	0.57
R14	53°23'15.8"N 1°28'48.7"W	Single sided	34.1	15	69.4	7.33	0.60	0.082	4.60	0.62	3.27	0.65
R15	53°23'18.1"N 1°28'51.4"W	Staggered	37.33	15	79.7	4.64	0.40	0.086	3.72	0.78	2.83	0.44
R16	53°23'20.4"N 1°29'07.4"W	Single sided	22.6	10	51.3	7.46	3.77	0.506	5.25	3.01	3.47	0.85

Note: Roads labelled R1 to R7 were those included in a field study 1 where they were labelled R2 to R8 respectively.

5.2.2. Photometric measurements

The lighting measurements in the 16 locations were carried out on the 15th of February 2019, between 19:00 and 22:00 (after sunset, which occurred at 17:15) and the weather was dry and partly cloudy. This was done resorting to the equipment and method described in section 4.2.1 (Appendix B). The data collected were used to establish the arithmetic mean illuminance, minimum illuminance, and illuminance uniformity (minimum/mean) at each location (Table 21), for horizontal, hemispherical, and semi-cylindrical illuminances. The arithmetic mean was calculated using ten equally spaced lighting data points, except when the distance was above 30 meters between lamp poles according to the BS EN 13201-3:2015 guidance. Table 21 displays the number of data points used per road.

The lighting measurements led to a total of 394 data points for all 16 test locations (Appendix F). A linear regression showed that horizontal illuminance has a relatively low association with hemispherical ($R^2 = 0.49$, $p= 0.000$) and semi-cylindrical illuminances ($R^2 = 0.39$, $p=0.000$). On the other hand, the relationship between hemispherical and semi-cylindrical illuminances is $R^2 = 0.77$ ($p= 0.000$). Although all these associations are significant, the level of explained variance might suggest reassurance appraisals be related differently to these metrics. Thus, this will be explored in further analyses. Examining the Shapiro-Wilk normality test, lighting data, similarly, to the field study 1, is not normally distributed, presenting for each mean illuminance $p < 0.001$.

5.2.3. Sample

Thirty-five test participants were recruited through the University of Sheffield volunteers' mailing list. One participant was dropped, post-hoc, as their responses to the bogus question, a question to check attention suggested unsatisfactory attentiveness.

One bogus question was included in each questionnaire, providing a total of 1120 responses (35 subjects evaluated 16 locations in 2 sessions – day and after-dark). Bogus questions should be answered by every participant in the same way (Meade and Craig 2012). Although 95.8% of responses were as expected, which according to Woods (2006) suggests conscientious answering, this was lower than in the first field study (99%). Woods (2006) verified that for a 1-factor model, 5% of careless response produced fairly well-fitted models independently of the sample size. One possible reason for the careless responding, in field study 2, is that the sessions took at least one more hour in length than in field study 1. Thus, responses could have been influenced by boredom or tiredness (Meade and Craig 2012).

There were 47 incorrect responses to the bogus question, of which 16 were after dark and 31 in the daytime. While most participants tended to provide at least one wrong answer at some point in the experiment, one individual provided eleven wrong answers to the daytime survey. This accounts for 69% of this participant's answers during the daytime. Thus, responses resulting from this participant were excluded from the analysis, leading to a final sample of 34 participants. Excluding this test participant, an accuracy of 96.7% indicates attentive responding.

The final sample included 34 individuals. Participants were aged between 18 and 33 years (mean=24.0); sixteen were male and eighteen were female. Following the day-dark approach, a repeated-measures within-subjects design was adopted. This means that all participants rated all 16 test locations both during daytime and after-dark conditions.

A post-hoc test assuming ANOVA was performed to test the sample size effect using G*Power software. For the final sample of 34, the effect size of 0.52 is a medium size effect (Cohen 1992), with a statistical power of 0.83 (Cohen's f) (Fotios, Monteiro & Uttley 2019).

5.2.4. Questionnaire design

The questionnaire from the field 1 study was used but with a single amendment. The daytime version included eleven questions instead of ten. As in field study 1, the after-dark version considered an additional five lighting-related items (road lighting quality, brightness, glare, apparent spatial distribution and overall satisfaction). Similarly to the previous version: one question was used to check attentiveness while responding, five questions related to contextual cues (*I can see clearly around me; Apart from the researcher and any other participants, there are lots of other people on the street; This street is kept in good condition; I can see a lot of litter and rubbish on this street; and, How familiar are you with this particular street?*).) and four to the three aspects of personal reassurance (cognitive: *How safe do you think this street is?, How risky do you think it would be to walk alone here at night?*; emotional: *How anxious do* *you feel when walking down this street?*; behavioural: *I would rather avoid this street if I could*) (Appendix C). All items were answered on a 6-point scale.

The original questionnaire included the question "*How risky do you think it would be to walk alone here at night?"*. For the second field study, this question was retained, but a second version was added which excluded the phrasing "*at night*". As discussed in the literature review (section 3.2.) this phrasing, used during the daytime, mandates participants to either imagine or recall the visibility or darkness in these locations. This item was included then to investigate the differential cognitive evaluation of the space in daytime and after dark, and the described methodological issue in section 3.2. The implications to these evaluations will be examined in chapter 6.

Furthermore, due to the increase in test locations (from 10 to 16), the bogus question pool was extended from 16 to 26 (Figure 17).

Figure 17. The pool of 26 bogus questions.

I was born after 1879
I shower more than once a month
I have never been to other planets
I own a pen
I am wearing clothes
I usually sleep more than one hour per night
I can name the 1831 world cheeses by heart
I have never been to Mars
I have watched a film at least once in the last 10 years
I am a werewolf
I have never read a book
I have never been to the Arts tower in Sheffield
I have never been to other planets
I haven't personally met Einstein

I have visited every country in the world
I always walk barefoot in the street
I have never seen water
I speak 35 different languages
I eat cauliflower every day
I never had a cold
I personally met Shakespeare
I have never been to Sheffield
I know how to read
I am a vampire
I eat anchovies absolutely everyday
I ride a unicorn on my way to the Uni
I have never filled a questionnaire
I own at least one pair of footwear

A random bogus question allocated to each questionnaire. This question is meant to be answered in the same manner independently from the participant. For example, "I have never been to the Arts Tower in Sheffield" is expected to be answered as 1 – strongly disagree, as the gathering point for every session of this study was inside this building.

5.2.5. Procedure

The field study was carried out between the 14th and 21st of November 2018. The participants took part in two sessions – one in daytime and another after-dark – each of approximately two hours of duration. Five days were allowed between the daytime and after-dark sessions. The daytime sessions started around 10:30 and the after-dark sessions after 18:00, following sunset at approximately 17:00.

The 16 test locations were visited in six groups of approximately six participants. The starting session and the route were counterbalanced (Table 22). The three routes allocated were never repeated for the same daytime condition. For three groups their starting session was in daytime and for the other three groups it was after dark.

Table 22. Groups starting session and routes used in the field study.

Group	**A**	**D**	**B**	**E**	**C**	**F**
Starting session*	**DT**	**AD**	**DT**	**AD**	**DT**	**AD**

	Route		
Order in which streets are visited	**A**	**B**	**C**
1	R9	R10	R16
2	R5	R11	R1
3	R8	R12	R15
4	R3	R7	R14
5	R7	R6	R4
6	R10	R2	R13
7	R11	R13	R2
8	R12	R16	R6
9	R6	R1	R8
10	R2	R4	R5
11	R13	R14	R9
12	R15	R15	R3
13	R14	R8	R10
14	R4	R5	R7
15	R1	R9	R11
16	R16	R3	R12

DT = Daytime; AD = After dark

During the session, the participants were asked to walk a specific segment of each test location; usually between two lamp posts, crossing, walking back, and ending parallel to the starting point. After experiencing the environment in the location, participants would fill in the questionnaire.

5.3. Results

The analyses in this chapter are focused on the day-dark difference. Thus, the difference between daytime and after-dark ratings for each variable in each location within subjects was calculated, resulting in a N=544 sample (16 locations, 34 test participants). The mean daytime and after-dark ratings are presented in Appendix H.

5.3.1. Is uniformity a better reassurance predictor?

Following the same method described in section 4.3.2., a composite rating was built considering the weight of the cognitive, emotional, and behavioural variables of reassurance and the other questions that refer to environmental aspects. This was done by performing a Principal Component Analysis (PCA), which is an analysis that scrutinizes the correlation between variables and clusters them into components that are measuring the same underlying dimension (Field 2009). For the Principal Components analysis, no rotation solution was selected. The Kaiser-Meyer-Olkin (KMO) test assesses the appropriateness of using PCA on a dataset (Hutcheson & Sofroniou 1999). The result of sample adequacy of the KMO test is 0.767 for our dataset. Values between .70-.79 mean that the sample is acceptable (Hutcheson & Sofroniou 1999; Field 2009).

The component scores were produced through the *regression method*. From this analysis four components were extracted (Table 23). The present work considers only the first component extracted, which was labelled *Reassurance* (Table 24).

Table 23. Components extracted in the Principal Component Analysis and respective loadings > 0.4.

Variables	**Component 1**	**Component 2**	**Component 3**	**Component 4**
Safe	0.811	-	-	-
Walk alone	0.762	-	-	-
Avoid street	0.725	-	-	-
Anxious	0.643	-	-	0.420
See clearly around	0.537	-	-	-0.564
Good condition	0.523	0.405	-	-0.481
Lots of people	0.279	-0.588	-	-
Litter and rubbish	-	0.793	-	-
Familiarity	-	-	0.873	0.400

Table 24. Component Matrix extracted for component 1 using Principal Component Analysis and component scores.

Survey question	Component loading	Component score
How safe do you think this street is?	0.811	0.281
How risky do you think it would be to walk alone here?	0.762	0.264
I would rather avoid this street if I could	0.725	0.251
How anxious do you feel when walking down this street?	0.643	0.223
I can see clearly around me	0.537	0.186
This street is kept in good condition	0.523	0.181
Apart from the researcher and any other participants, there are lots of other people on the street	0.279	0.097
I can see a lot of litter and rubbish on this street	0.247	0.086
How familiar are you with this particular street?	0.098	0.034

The composite rating was calculated using the component scores shown in Table 25 to weight each variable rating of each participant per location. Then, the composite rating was averaged per location. The minimum and maximum possible composite score is ±7.51. For an easier comparison with previous results, these composite scores were standardized to the scale of a minimum and maximum day-dark difference of ±5, using *z*-scores (Field 2009) (equation 3, section 4.3.2.). Table 25 shows the original composite rating and the subsequent transformed composite rating and its standard deviation for every test location.

Table 25. Mean composite reassurance day-dark difference scores.

Location	Composite score		Transformed composite score	
	Mean	Std dev	Mean	Std dev
Road 1	1.68	1.22	1.20	0.91
Road 2	1.24	1.43	0.37	1.07
Road 3	0.14	1.54	0.42	1.15
Road 4	0.49	1.64	0.49	1.22
Road 5	1.01	1.15	0.16	0.86
Road 6	0.47	1.16	0.12	0.87
Road 7	0.04	1.51	1.37	1.13
Road 8	0.20	1.17	0.01	0.87
Road 9	0.53	1.11	0.17	0.83
Road 10	2.05	1.43	0.62	1.07
Road 11	2.09	1.34	0.44	1.00
Road 12	1.98	1.38	0.62	1.03
Road 13	1.94	1.27	0.29	0.95
Road 14	1.96	1.22	0.51	0.91

Road 15	1.88	1.61	0.83	1.20
Road 16	1.74	0.88	0.32	0.65

A better road lighting effect is shown by lower composite ratings which indicate a lower difference in day-dark difference in evaluated reassurance. Table 26 shows the relationship between horizontal, hemispherical, and semi-cylindrical illuminances (mean, minimum and uniformity) and this standardised composite score. A logarithmic function was used as it was the best fit for the data. The Shapiro-Wilks test showed a normal distribution of the composite rating (*p* = 0.075).

Table 26. Goodness of fit of logarithmic function to explain composite rating plotted against horizontal, hemispherical, and semi-cylindrical illuminance mean and minimum, and uniformity of horizontal illuminance. (N=16).

Illuminance measure	**Horizontal**		**Hemispherical**		**Semi-cylindrical**	
	r^2	**p-value**	**r^2**	**p-value**	**r^2**	**p-value**
Mean	0.56	0.001	0.66	0.000	0.52	0.002
Minimum	0.52	0.002	0.48	0.003	0.40	0.008
Uniformity	0.17	0.117	0.05	0.387	0.08	0.297

Table 26 displays a minor difference with regards to the significance of the association of each illuminance with the composite rating. However, mean hemispherical illuminance presents the highest correlation with the reassurance composite. Figures 18 to 20 show the graphical representation of the composite ratings plotted against the diverse lighting metrics. The lighting predictive effect over reassurance is nonlinear, thus the best-fit lines assume a logarithmic function. This function also stabilises the variance of the lighting data, which is not normally distributed (Chattamvelli & Shanmugam 2015; Chatterjee & Hadi 2012). Figure 18 displays the curve of the different means from horizontal, hemispherical, and semi-cylindrical illuminances, while Figure 19 shows the association with the minima and Figure 20 the association with the uniformities.

Figure 18. Composite rating plotted against horizontal, hemispherical and semi-cylindrical averages assuming a logarithmic function.

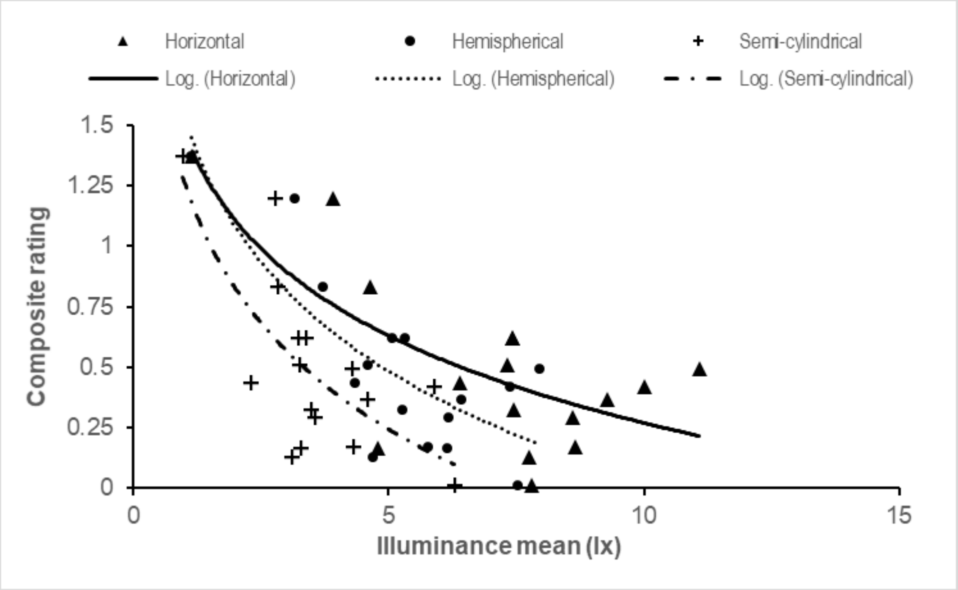


Figure 19. Composite rating plotted against horizontal, hemispherical and semi-cylindrical minima assuming a logarithmic function.

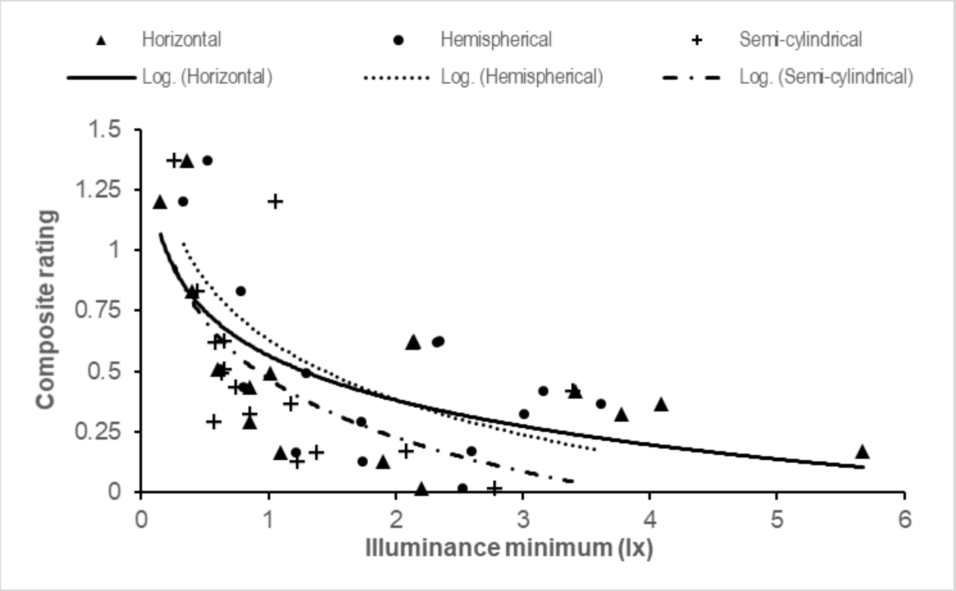
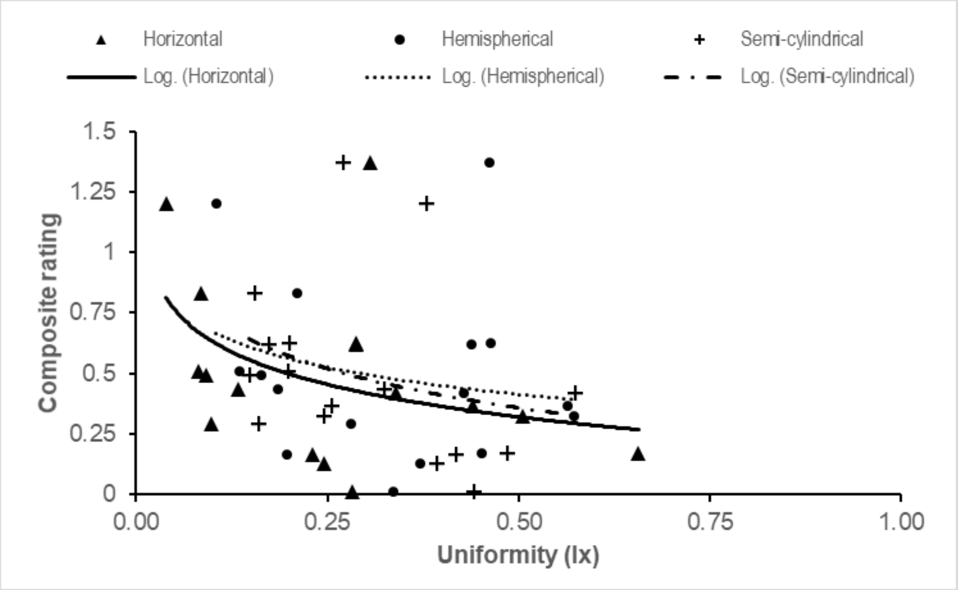


Figure 20. **Composite rating plotted against horizontal, hemispherical and semi-cylindrical uniformities assuming a logarithmic function.**



Opposing to the hypothesis drawn from results of the first field study (section 4.3.2.), these results show that mean horizontal illuminance (R^2= 0.56, *p*=0.001) presents a higher association with reassurance than does uniformity (R^2=0.17, *p*=0.117). The relationship of minimum horizontal illuminance to reassurance seems to be sustained (R^2=0.52; *p*=0.002) at a similar level of significance. Hemispherical and semi-cylindrical measures reiterate this tendency of a higher association of means with reassurance ($\bar{E}_{sc}$ R^2= 0.52, *p*=0.002; $\bar{E}_{hs}$ R^2= 0.66, *p*=0.000) followed by an equally strong association of minima ($E_{sc,min}$ R^2=0.40, *p*=0.008; $\bar{E}_{hs,min}$ R^2= 0.48, *p*=0.003). Overall, hemispherical mean appears to be the best predictor of reassurance.

A series of nonlinear regression models assuming the logarithmic fit with one or two predictors were examined. Table 27 presents the models using a single term for all significant measures of horizontal, hemispherical, and semi-cylindrical illuminances, and horizontal uniformity to establish a parallel with previous results. As expected, the mean values of each of the three metrics and horizontal minimum provide a better model when only one variable is considered. Assuming that the best model is the simplest, only the most significant single terms were considered in Table 28 for models combining two terms.

Table 27. Results from multiple regression models using the single metrics of horizontal, hemispherical and semi-cylindrical mean and minimum, and horizontal uniformity to predict the transformed composite day-dark difference score of reassurance (N=16).

Illuminance measure used as predictor	Constant	Coefficient	Individual predictor p-value	Model R^2 *	Overall model p-value	AIC
Horizontal Mean	1.4678	-0.52	0.001	0.56	<0.001	-41.69
Horizontal Minimum	0.5654	-0.267	0.002	0.52	0.002	-40.12
Horizontal Uniformity	0.184	-0.194	0.117	0.17	0.117	-31.42
Semi-cylindrical Mean	1.265	-0.6362	0.002	0.52	0.002	-40.29
Semi-cylindrical Minimum	0.4686	-0.3495	0.008	0.40	0.008	-36.73
Hemispherical Mean	1.532	-0.652	<0.001	0.66	<0.001	-45.72
Hemispherical Minimum	0.63	-0.358	0.003	0.48	0.003	-39.00

Table 28. Results from multiple regression models using combinations of the most significant individual illuminance measures to predict the transformed composite day-dark difference score of reassurance (N=16).

Illuminance measure used as predictor	Constant	Coefficient	Individual predictor p-value	Model R^2 *	Overall model p-value	AIC
Horizontal Mean + Horizontal Minimum	1.17	-0.34 -0.15	0.035 0.073	0.61	0.001	-41.47
Horizontal Mean + Semi-cylindrical Mean	1.52	0.058 -0.71	0.858 0.074	0.61	<0.001	-41.44
Horizontal Mean + Hemispherical Mean	1.45	-0.347 -0.252	0.197 0.449	0.52	<0.001	-38.10
Horizontal Minimum + Semi-cylindrical Mean	1.02	-0.16 -0.398	0.05 0.05	0.59	<0.001	-40.72
Horizontal Minimum + Hemispherical Mean	1.29	-0.131 -0.478	0.072 0.006	0.70	<0.001	-45.54
Hemispherical Mean + Semi-cylindrical Mean	1.57	-0.853 0.237	0.032 0.554	0.62	<0.001	-41.85

Considering that the highest R^2 and the lowest p-value of the model in parallel with the lowest Akaike Information Criterion value, offer a better prediction power, results suggest that hemispherical mean illuminance is the most fit predictor term. However, the combination of hemispherical mean illuminance and minimum horizontal illuminance offers a slight improvement in the reassurance prediction. The models are expressed in equations 6 and 7.

Equation 6. Predictive model using hemispherical mean illuminance (model 3).

$$Composite\ rating = 1.532 - 0.652\ ln(\bar{E}_{hs})$$

Equation 7. Predictive model using horizontal minimum illuminance and hemispherical mean illuminance (model 4).

$$Composite\ rating = 1.29 - 0.131\, ln(E_{min}) - 0.478\, ln(\bar{E}_{hs})$$

The models described by the equations 3 and 4, referred to as Model 1 and Model 2 respectively, were used to predict the necessary illuminances for a given day-dark difference. Table 29 indicates the estimation for Model 3 only, thus using the hemispherical mean illuminance as a single term. The Model 4 estimations considering hemispherical mean and horizontal minimum illuminances are reported in Table 30. This table reports three possible combinations of the terms for a given day-dark difference. The first combination is based in the results from model 3 (Table 29), the second is based in the minimum horizontal illuminance reportedly needed in the field study 1 for a day-dark difference of 0.5 units for N=8 (section 4.3.2.) and finally, the third combination considers the minimum horizontal illuminance value given in BS EN 13201-2:2015 for P3 class (Table 1). The P3 class was chosen, as the value accomplished in the first field study accounts for the P2 class, which were the coincident classes with previous estimations for a 0.5 day-dark difference. Furthermore, the metric levels of the present test locations seem to associate better with these Pedestrian road classes.

Table 29. Hemispherical illuminances estimated according to day-dark differences of 0.25, 0.5, 0.75- or 1.0-units using Model 3.

Day-dark difference	Model 3
	Hemispherical mean illuminance
1	2.25
0.75	3.3
0.5	4.85
0.25	7.1

Table 30. Combination of hemispherical mean and horizontal minimum illuminances estimated according to day-dark differences of 0.25, 0.5, 0.75- or 1.0-units using Model 4.

	Model 4							
Day-dark difference	1		0.75		0.5		0.25	
	Emin	*Ēhs*	*Emin*	*Ēhs*	*Emin*	*Ēhs*	*Emin*	*Ēhs*
	0.5	2.25(1)	0.8	3.3(1)	1.3	4.85(1)	2.2	7.1(1)
	2.1(2)	1.4	2.1(2)	2.5	2.1(2)	4.3	2.1(2)	7.2

1.5(3)	1.5	1.5(3)	2.75	1.5(3)	4.65	1.5(3)	7.85

(1) forced entry values considering the results from the previous model

(2) forced entry values considering the results from field study 1

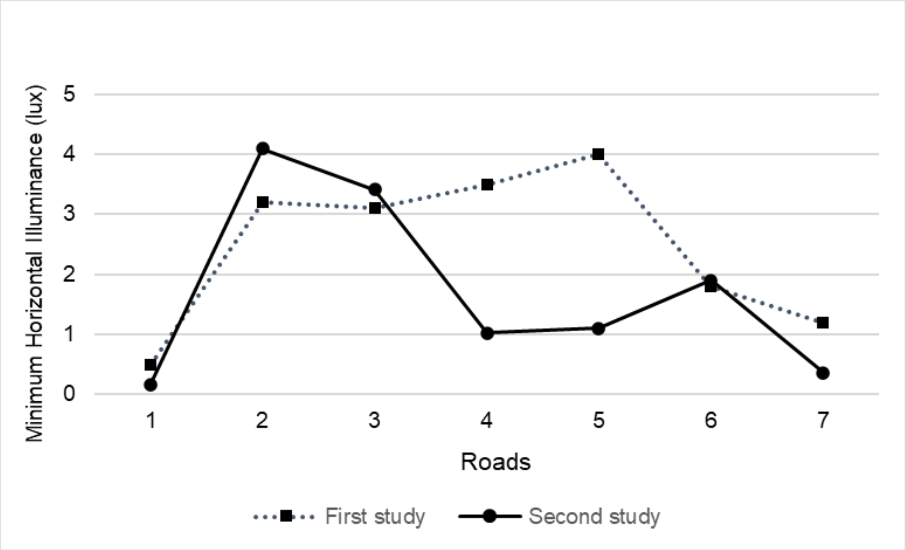
(3) forced entry values considering BS EN 13201-2:2015 values for P3 class

A reduction of the day-dark difference to 0.5 units is estimated for 4.85 lux of hemispherical mean (Table 29). Using the same mean hemispherical value in Model 4 indicates that a minimum horizontal of 1.3 lux would be required for a day-dark difference of 0.5. Two other combinations of terms suggest that for a P2 class a hemispherical mean illuminance of 4.3 lux should be maintained and for a P3 class the same illuminance should be of 4.65 lux. The rise in lighting levels to obtain a 0.25 day-dark difference is considerable in terms of mean hemispherical illuminance. These results show that reassurance appraisals are dependent of the association of the terms, indicating that the lowest the hemispherical mean, the highest should the horizontal minimum be.

5.3.2. Are there significant differences between field study 1 and 2 illuminances and appraisals?

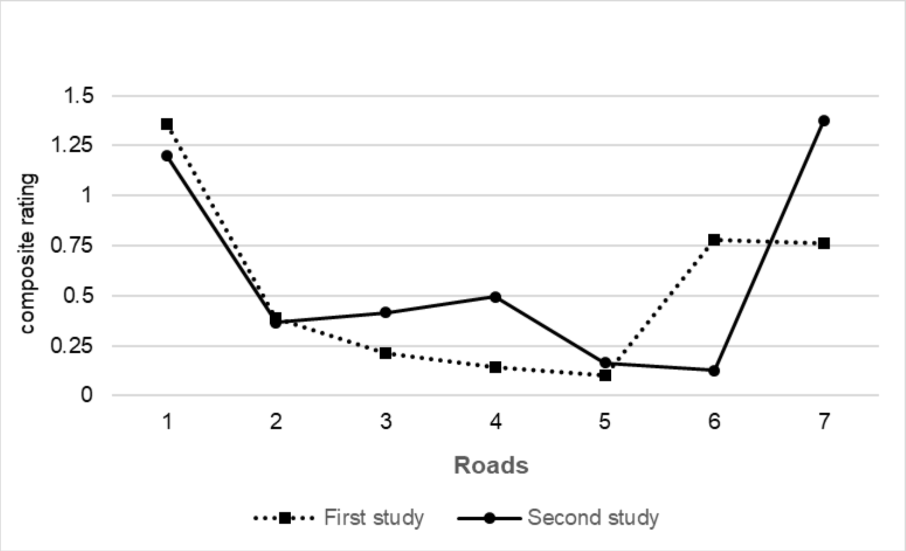
Seven test locations from the first field study were also used in the second field study. These locations underwent a re-lighting of the road installations to LED arrays between the first study and the present study. Due to the apparent relevance of minimum horizontal illuminance for reassurance in both studies, Figure 21 shows a comparison of the horizontal minimum illuminances in those locations. It is important to highlight that the location labelling used is adopted in the present chapter (R1 to R7) rather than those used in chapter 4 (R2 to R8). Figure 22 displays a comparison between the reassurance composite in the first and second studies for N=7.

Figure 21. Contrast between the first and second field study horizontal illuminance minimum for N=7.



The comparison of minimum horizontal illuminances in Figure 21 shows that minimum horizontal illuminances in R1 and R6 were the same for both field studies, whereas in the second field study the minimum illuminances were higher for R2 and R3, and lower for R4, R5 and R7.

Figure 22. Contrast between composite ratings from first and second field study for N=7.



While locations R1, R2 and R5 produced similar safety evaluations, the day-dark difference increased in R3, R4 and R7. Satisfactory appraisals were produced consistently in R2 and R5 (between 0.15 and 0.40), however displaying a fluctuation in the minimum horizontal illuminance. The R6 location decreased considerably the day-dark difference in the second study but maintained the minimum horizontal illuminance. Following the premise that lighting can only allow the safety after-dark as felt in the daytime, Figure 23 to 25 show the safety, avoidance and anxiety daytime ratings comparison.

Figure 23. Contrast between safety daytime ratings from first and second field study for N=7.

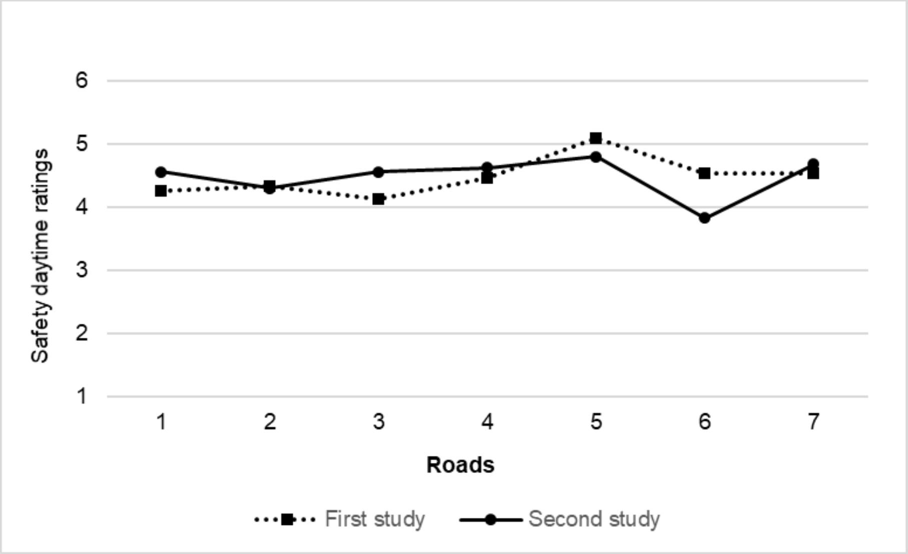


Figure 24. Contrast between avoidance daytime ratings from first and second study for N=7.

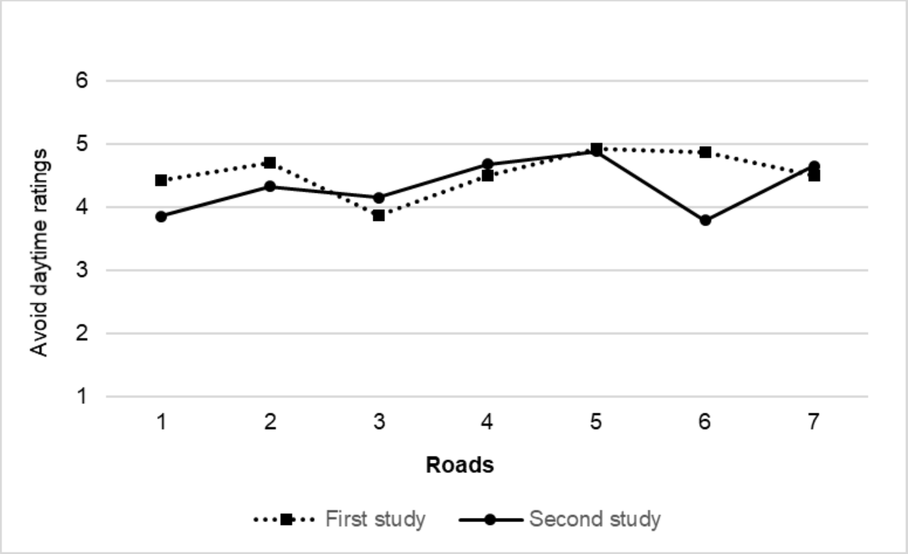
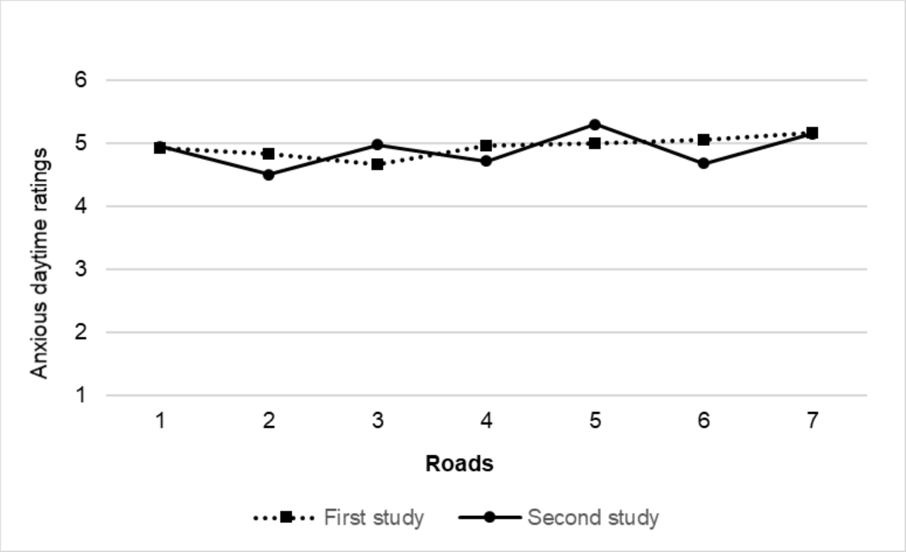


Figure 25. Contrast between anxiety daytime ratings from first and second study for N=7.



Figures 23 to 25 suggest that the lower composite rating in R6 despite the same recorded minimum horizontal illuminance to be affected by a lower self-reported reassurance in the location during the daytime. This means that road lighting in place would have a lower daytime reassurance threshold to reach. Another potential explanation is that a combination of terms might account for and predict better reassurance. Hemispherical illuminances from study 1 are reported in Table 7 (section 4.2.1. R2 to R8, labelled respectively R1 to R7 in this section).

Thus, an independent samples Mann-Whitney U test was done to compare if there are significant differences in recorded horizontal, hemispherical, and semi-cylindrical mean illuminances in each street. Due to the relighting the distance between lamp poles was increased in some locations, thus the number of illuminance data points is distinct between field study 1 and 2. Results for horizontal, hemispherical and semi-cylindrical mean illuminances are reported in Table 31. A significance of <0.05 indicates that the null hypothesis is rejected, thus indicating a significant difference in the recorded metrics in each street.

Table 31. Independent samples Mann-Whitney U test to identify significant differences between the mean illuminances recorded in field study 1 and 2 (N=7).

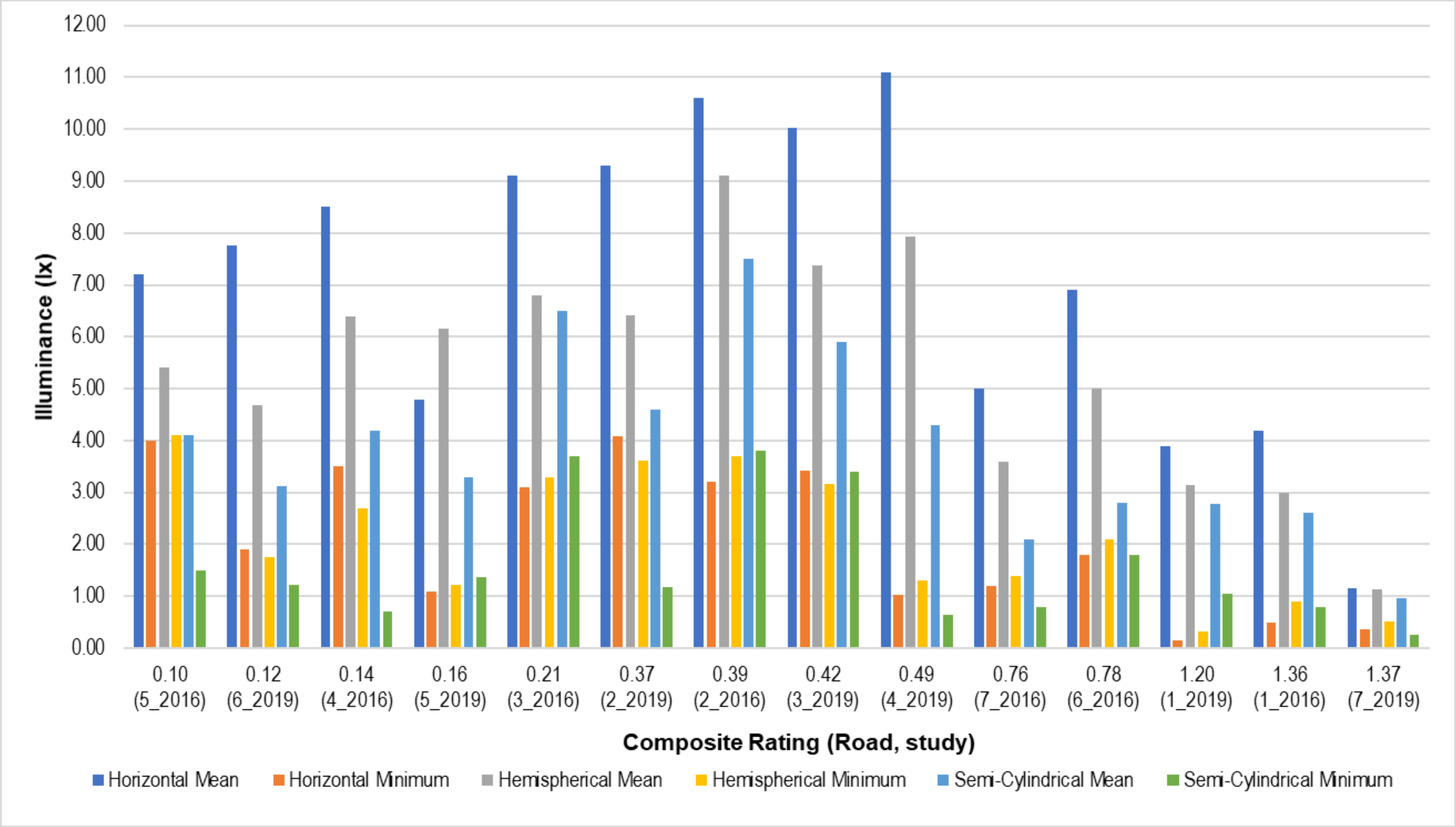
	Horizontal	**Hemispherical**	**Semi-cylindrical**
Road	*p*	*p*	*p*
1	0.440	0.352	0.104
2	0.007	0.253	0.072
3	0.045	0.342	0.006
4	0.000	0.440	0.031

5	0.000	0.049	0.640
6	0.003	0.659	0.000
7	0.000	0.000	0.008

Results show that R5 only has significant difference in horizontal mean illuminance (first study m = 7.22; second study m = 3.29). However, if Figure 24 is considered, these changes do not seem to affect the composite rating. On the other hand, R7 shows a consistent difference throughout the three mean illuminances, reporting significantly lower mean illuminances in the second field study. Between the first and second field study lighting levels a pattern of lower horizontal mean illuminance and higher semi-cylindrical mean illuminance is observable, with the exception of R1 and R5. This could also explain the considerable decrease in the composite rating day-dark difference (from 0.75 units to ⩽0.25 units). Performing independent samples Mann-Whitney U test on the standardised composite scores showed that R6 and R7 are the only locations that present significant differences (p= 0.014 and p=0.34, respectively) in levels of reassurance reported in field study 1 and 2.

These results seem to confirm that the impact of road lighting is affected by the level of reassurance felt during daytime in the locations. Furthermore, it seems that a threshold for each metric is to be studied, as well as the interaction between these lighting levels. Figure 26 shows graphically the lighting levels in each location attending to recorded day-dark differences.

Figure 26. Bar graph plotting illuminances per location according to the reassurance composite. Locations are organised by the overall rating of reassurance and numbered with the location ID and year (2016=field study 1 and 2019=field study 2).



The bar graph shows that locations in field study 1 or 2 that display a higher day-dark difference (>0.5) when a combination of lower illuminances is in place. This suggests that the single variation of each metric has a subsequent impact on the overall lighting, thus affecting reassurance. Following the determination that daytime ratings could have influenced the day-dark difference in R6, it is observable that a day-dark difference above 0.5 units was always recorded when a semi-cylindrical mean illuminance below 3 lux was verified. Furthermore, a day-dark difference seems to increase (> 0.5) when hemispherical mean illuminance is below 4 lux. This confirms the regression modelling results from section 5.3.2 that pointed out to a hemispherical mean of 4.85 lux needed for a 0.5 day-dark difference, in a 6-point rating scale.

Finally, it is important to note that R4 and R5 had, in both studies, LED lamps. Though the day-dark difference was found to be the lowest for N=7 in field study 1, R4 in field study 2 increased its day-dark difference. Although, this difference in the composite was not found to be significant (p=0.107), is still on a 0.5-unit threshold, it is to be noted that higher contrast between metric levels can be found.

Using the regression models described in 5.3.1, thresholds of potential optimal illuminance in different metrics were found (Table 32).

Table 32. Estimations of horizontal, hemispherical, and semi-cylindrical illuminances for a day-dark difference of 0.5 and 0.25 units.

Illuminance (lx)	**Day-dark difference**	
	0.5	**0.25**
Horizontal mean	6.50	10.60
Horizontal minimum	1.20	3.30
Hemispherical mean	4.85	7.1
Hemispherical minimum	1.4	2.9
Semi-cylindrical mean	3.3	4.9
Semi-cylindrical minimum	0.9	1.8

These estimations indicate slightly lower horizontal mean and horizontal minimum illuminances than the predicted in field study 1 (section 4.3.3.). Horizontal mean illuminance is set at 6.50 lux rather than 7 lux, and horizontal minimum illuminance at 1.20 lux rather than 2.1 lux. Nevertheless, it is plausible that this is due to an increase in the semi-cylindrical mean illuminance, as implied by results in Table 31 (section 5.3.2.). Estimations from field study 2 confirm the inferences from Figure 26 analysis, setting the optimal threshold for semi-cylindrical mean illuminance above 3 lux.

5.4. Discussion

A second field study was conducted to look at the exploratory findings of field study 1. This study replicated the method adopted but expanded the sample and the number of test locations. While field study 1 had ten locations, including a park pathway and an underpass, this study considered residential roads only. Seven initial roads were retained, and nine extra locations included. Preserving seven of the original locations allowed to determine any disparity in reassurance levels. The selected area experienced a relighting between both studies, as part of the *UK Road Investment Strategy* commencing in 2015/2016 running until 2019/2020 (Department for Transport 2015).

This study attempted to confirm the minimum horizontal illuminance and uniformity as best predictors for self-reported levels of reassurance. Moreover, the relationship of reassurance with hemispherical and semi-cylindrical illuminances were also assessed. While in the previous study horizontal illuminances seemed to be highly associated with hemispherical and semi-cylindrical, this is more arguable in the second field study, as the association reported significant p-values but low correlation.

Contrarily to previous findings, uniformity presented a non-significant relationship to reassurance ($R^2=0.17$, $p=0.117$), even though the range of uniformities provided was substantial (from 0.039 to 0.656 lux), whereas mean and minimum horizontal, hemispherical, and semi-cylindrical illuminances displayed significant associations. The link between uniformity and feelings of safety has been established in other studies (Haans & Kort 2012; Narendran, Freyssinier & Zhu 2016; Nasar & Bokharaei 2017; Bullough, Snyder & Kiefer 2019), however mainly not in residential roads, but instead in car parks. The differential nature and function of the space is then to be considered. In the case of residential roads, it seems that other metrics are more consistent in determining pedestrian reassurance.

Another relevant acknowledgement is that following the new lighting installations, every lamp source was changed to LED. Therefore, it is possible that colour rendering and/or lamp source has an effect on reassurance. While literature linking reassurance to these aspects is scarce, Knight (2010) found whiter light to enhance perceptions of safety. Although these elements are acknowledged as perhaps impacting results, they are not examined in the present research.

Attempting to define the threshold for an optimum illuminance, regression models were tested. These confirmed hemispherical mean illuminance as the best predictor ($p<0.001$) but mean ($p=0.001$) and minimum ($p=0.002$) horizontal illuminance were also significant. Although the significance of hemispherical mean illuminance was not an *a priori* hypothesis, this was suggested as the best overall regression fit. Thus, two models were selected: the first considering hemispherical mean illuminance only, and the second considering hemispherical mean and horizontal minimum illuminance, as this provided the second-best fit attending to the Akaike Information Criterion (AIC = -45.54). Both models provided estimations for a day-dark difference of 1, 0.75, 0.5 and 0.25 units.

Using *model 3* (Equation 6) to estimate a day-dark difference at 1, 0.75, 0.5 and 0.25 unit, the mean hemispherical illuminance defined was of 2.25 lux, 3.3 lux, 4.85 lux and 7.1 lux, respectively. These results were then used to predict the minimum horizontal illuminance needed for such levels, using *model 4* (Equation 7). This was done through a forced entry method. This was repeated by entering horizontal minimum illuminance at 2.1 lux, which is the level estimated for a 0.5 day-dark difference (section 4.3.3) and at 1.5 lux, which is the defined minimum horizontal for a P3 class.

While adequate lighting should account for the road users' needs, optimal lighting should be adequate but energy efficient. Therefore, a day-dark difference reduction to 0.25 would be impractical considering that 7 to 7.85 lux of mean hemispherical illuminance would be required. However, understanding the interaction between metric levels and its impact on reassurance could benefit from further study.

Comparing the set of metrics in the repeated locations in both studies (N=7) seems to suggest that the defined hemispherical mean of 7 lux for a 0.25 day-dark reduction can be surmounted if other metrics are accounted for. This seems to be the case of accounting for semi-cylindrical illuminance, which was increased after the relighting of the locations, leading to higher reassurance when registered over 3.3 lux. This is identified as one potential influence in results on R6. In field study 2, the day-dark difference dropped significantly from 0.78 (field study 1) to 0.12 ($p= 0.014$). Although examining the responses in the daytime to the three items related to reassurance (safety, anxiety, and avoidance) it seems that in field study 2 this location was reported to be not as reassuring as before. This means that the target to be met by road lighting would be lower, thus explaining the drop in the day-dark difference.

From this perspective, it is important to note that 10 lux of horizontal mean illuminance has been pointed out as a plateau after which reassurance seems to evidence little improvement (Narendran, Freyssinier & Zhu 2016; Bullough, Snyder &

Kiefer 2019; Bhavagavathula & Gibbons, 2020). However, field study 1 and 2 results evidence that an acceptable decrease in day-dark difference (< 0.5) is verified at 6.5 to 7.1 lux (section 4.3.3 and 5.3.1.). These results seem to reinforce the need to consider lighting levels as a dynamic arrangement rather than focusing on a single metric.

For a reduction of the day-dark difference to 0.5 units, in a 6-point rating scale, 4.3 to 4.85 lux would be required for 1.3 to 2.1 lux of horizontal minimum illuminance, which is the approximate set level for P2 and P3 lighting classes. The hemispherical mean illuminance though corresponds to the highest defined class (Table 1). The horizontal mean illuminance for P2 and P3 is defined as 7.5 and 10 lux respectively. The current British Standards (BS EN 13201-2:2015) divide the hemispherical mean illuminance between three classes (HS3 to HS1), ranging from 1 to 5 lux; while semi-cylindrical ranges between 0.2 to 5 lux (P6 to P1). Therefore, it is key to question whether it would be beneficial to lower some horizontal mean illuminances thresholds while increasing the lowest acceptable level of hemispherical and semi-cylindrical mean to over 3 lux.

Semi-cylindrical and vertical illuminances are defined as relevant if facial recognition is needed (BS EN 13201-2:2015). Nevertheless, this is likely to be fundamental for reassurance, as interpersonal judgements are made at a distance to allow an adequate response or behaviour in case of detected threat (BS EN 13201-2:2015). In a study carried out in a residential setting with LED lighting, for a 10 lux mean horizontal illuminance, a vertical minimum illuminance of 1.4 lux was pointed out as necessary for satisfactory facial recognition tasks at a 4 m distance (Ailin et al. 2019). Defining a more aligned approach of road lighting to pedestrian needs in residential areas should take place. The lack of orientation of lighting levels for pedestrian needs is highlighted by Fotios (2019). Besides the need to feel reassured and making interpersonal judgments after dark, there is also the need to detect and avoid obstacles. Eye-tracking data seem to suggest that detection is made at an approximate distance of 3.4 meters (Uttley 2015). Fotios and Uttley (2018) found that the horizontal illuminance level that allowed pedestrians to detect a 10mm obstacle at 3.4m distance ranges from 0.22 lux up to 0.93 lux, depending on the pedestrian age and the S/P ratio. However, for obstacle detection, a plateau is reached at 2 lux, with no improvement verified at higher minimum horizontal illuminance (Uttley, Fotios & Cheal, 2017).

It is acknowledged that this research is pedestrian-need-focused, but there are other users, such as cyclists and drivers, who might have different needs. Nevertheless, it seems essential to first confirm the effects of different metrics, singularly and combined, and, potentially the S/P ratio to then frame current standards to fulfil these to a minimum acceptable and optimal level. This seems to be possible because when considering results for a day-dark difference of 1 unit (section 5.3.2), having a minimum horizontal illuminance of 1.5 or 2.1 lux, has little effect in reassurance, if the hemispherical mean is as low as 1.4-1.5 lux. Thus, this suggests that there is (1) a metric minimum acceptable and (2) an optimal level after which variation is insignificant.

5.5. Summary

In chapter 5, field study 2 was reported. This replicated and expanded the study from chapter 4. This was done by extending the number of participants and test locations while replicating the adopted method. Results confirm that minimum horizontal illuminance is relevant for predicting reassurance. However, horizontal uniformity is not confirmed as relevant. Hemispherical mean illuminance, on the other hand, seems to also be pertinent. Regression models were performed and served as a basis for a series of estimations (section 5.3.1.). Furthermore, due to the repeated test locations in field study 2, which underwent a relighting between studies, a comparison between previous and current conditions was outlined.

It argued that lighting should be accounted for as a dynamic between metrics, with optimal thresholds to ensure pedestrian reassurance of 6.50 lux of horizontal mean illuminance, 1.20 lux of minimum horizontal illuminance, 4.85 lux of hemispherical mean illuminance, 1.4 lux of hemispherical minimum illuminance, 3.3 lux of semi-cylindrical mean illuminance and 0.9 lux of semi-cylindrical minimum illuminance. These estimations were done considering each illuminance at a time, but as verified in the multiple nonlinear regression model used (Model 4) if more than one metric is considered, these thresholds could fluctuate.

.

Chapter 6. Real, imagined and perceived illuminance – does it matter?

6.1. Introduction

The focus of chapters 4 and 5 was the potential effect of different lighting metrics in the level of reassurance in pedestrians. These field studies analysed a set of metrics and their association to self-reported levels of safety attempting to establish the optimum levels of illuminance while examining potential methodological issues identified from previous studies (section 3.1., 3.3. and 3.4). The key topic addressed in the present chapter is the subjective assessment of lighting and the implications of increasing subjectivity in lighting studies by asking individuals to recall or imagine after-dark settings. This is done in two distinct sub-sections. The first focused in the methodological issue of evaluating a recalled or imagined after-dark environment (section 3.2.) and the latter dedicated in the self-reported evaluations of the road lighting. This chapter explores the data from the two previously reported studies to examine two theories:

1. Survey items that ask participants to recall or imagine after-dark safety impressions produce distinct results from an actual reported evaluation in such condition.
2. Subjective appraisals of lighting account for the real lighting conditions experienced in the provided locations.

6.2. Recalling or imagining the after-dark

Field study 1 and 2 included the survey item "*How risky do you think it would be to walk alone here at night*?" in both daytime and after-dark sessions. This item or a proxy has been used in previous studies (e.g. "*Use the scale below to rate how risky you it would be to walk alone here at night.*", Boyce et al. 2000). However, this evaluation in some studies was taken in laboratory settings or through phone interviews rather than in the real location at the represented time-of-day (Boomsma & Steg 2014; van Rijswijk, Rooks & Haans 2016; Nasar & Bokharaei 2017). Asking such an item requires either imagining or recalling the level of safety in a location or area. This is identified as a potential critical issue (see section 3.2.) because evaluations can be divergent depending on whether the individual is experiencing the environment in the real world or through other means (Bishop & Rohrmann 2003). While the after-dark evaluation could be based on direct experience, the daytime evaluation would require an imagination of the likely perception of risk after dark. In a study of the accuracy of memory associated with the brightness of lighting, it was shown that when sequentially evaluating lighting, it was remembered as less bright than before (Uchikawa & Ikeda 1986). In a daytime session, asking about risk at night therefore requires a response based on an imagining of the environment after-dark.

Recording daytime and after-dark assessments of test locations using different starting sessions allows an examination of the potential distortion of a recalled or imagined environment after-dark. The investigated hypothesis in this section is: individuals recall or imagine after-dark conditions as less reassuring than when experiencing it.

6.2.1. Field study 1

Two aspects were included in field study 1 to examine this hypothesis: (1) the underpass (R10) which presented the highest lighting levels but as an enclosed location during daytime hours did not present much daylight, and (2) a survey item that recorded in both time conditions the perceived risk of walking in locations after-dark (*How risky do you think it would be to walk alone here at night?*). The items were recoded to match the other questionnaires items, so a higher rating indicates higher reassurance (1 = Very risky to 6 = Not at all risky).

From the twenty-four participants that took part in field study 1, twelve started the experiment after-dark and twelve in daytime (recall section 4.2.5.). Thus, providing an imagined or recalled response in the daytime regarding the after-dark environment. The item rating scale was reversed to match the safety question, where a higher rating means a higher perceived safety, thus lower perceived risk (1= “*very risky*”; 6= “*not at all risky*”). The Shapiro-Wilks test did not evidence normality, displaying significant statistic at $p < 0.05$. Thus, nonparametric tests were used.

The data was analysed through a Wilcoxon signed rank test, which allows to compare two related samples. Therefore, data was divided by two groups; group 1 comprised of participants who had their first session in daytime and group two comprised of those who had their first session after-dark. The ratings in daytime and after-dark conditions in each group were examined and descriptive analysis reported in Table 33 and Ranks in Table 34.

Table 33. Descriptive analysis of the comparison of daytime and after-dark ratings to field study 1 item "walk alone at night".

	N	Mean	St. dev
Group 1			
Daytime ratings	120	4.18	1.539
After-dark ratings	120	3.62	1.298
Group 2			
Daytime ratings	120	3.63	1.335
After-dark ratings	120	3.94	1.343

Table 34. Wilcoxon signed-rank test of daytime and after-dark ratings to field study 1 item "walk alone at night".

	N	Mean Rank	Sum of ranks
Group 1			
Negative Ranks	58	48.29	2801.00
Positive Ranks	30	37.17	1115.00
Ties	32		
Total	120		
Group 2			
Negative Ranks	27	37.00	999.00
Positive Ranks	49	39.33	1927.00
Ties	44		
Total	120		

In Table 34, negative ranks indicate lower scores in after-dark than in daytime, positive ranks higher after-dark scores and ties stand for equal scores in both conditions. From the participants that rated locations for the first-time during day (group 1), thus having to imagine after-dark conditions, fifty-eight scores indicate that imagined the after-dark location as safer than when experiencing it, thirty evaluated the location as safer after-dark than imagined and thirty-two provided the same appraisal. For group 2, which is comprised of participants rating the after-dark condition first, twenty-seven scores indicated that locations are recalled in daytime as safer, forty-nine scores rated the same locations as safer when experiencing the actual conditions after-dark, and forty-four scores ranked the locations similarly. The Wilcoxon signed-rank test showed that there are significant differences in how individuals experience and imagine or recall after-dark conditions for both group 1 (Z = -3.580, p < 000.1) and group 2 (Z = -2.499, p = 0.012).

6.2.2. Field study 2

Exploring this matter further, in the second field study, the item "*How risky do you think it would be to walk alone here at night?*" was used in parallel to a proxy item that does not include the phrasing "at night". It is expected that participants were mindful of the questions posed, thus producing different responses to both items. The survey items were answered in a 6-point rating scale. Responses were reversed, so higher risk = 1 and not risky = 1.

This field study had a sample of 34 participants rating 16 test locations (recall section 5.2.). The Shapiro-Wilks test showed that the distribution of the data was not normal (p <0.05), thus nonparametric tests are to be applied.

Similarly, to section 6.2.1., participants were divided into two groups according to the starting session time of the day. Thus, group 1 started the field study during daytime, thus imagining after-dark conditions, and group 2 started after-dark, so recalling after-dark conditions in daytime. Group 1 is comprised of 15 participants, while group 2 is comprised of 19.

A Wilcoxon signed-rank test was used to compare responses to the "walk alone" survey items ("How risky do you think it would be to walk alone here *at night?"*; "How risky do you think it would be to walk alone here?"). This was done to compare responses between (1) walk alone at night in daytime and after-dark, (2) walk alone and walk alone at night in after-dark, and (3) walk alone and walk alone at night in daytime in each group. Comparing scores to the walk alone at night survey item between day and after dark allows to understand whether there is a significant effect of imagined or recalled darkness, while the comparison between the walk alone and walk alone at night across ratings in day and after-dark provides validation. During daytime these should produce different results and after dark should produce similar results. Table 35 displays the descriptive results, and Table 36 shows the Wilcoxon signed-ranks test results.

Table 35. Descriptive analysis of the comparison of daytime and after-dark ratings to field study 2 items "walk alone" and "walk alone at night".

	N	Mean	St. dev
Group 1			
Walk alone at night			
Daytime ratings	240	3.59	1.382
After-dark ratings	240	3.66	1.420
Walk alone			
Daytime ratings	240	4.37	1.338
After-dark ratings	240	3.75	1.394
Group 2			
Walk alone at night			
Daytime ratings	304	3.88	1.345
After-dark ratings	304	3.92	1.341
Walk alone			
Daytime ratings	304	4.17	1.254
After-dark ratings	304	4.56	1.225

Table 36. Wilcoxon signed-rank test of daytime and after-dark ratings to field study 2 items "walk alone" and "walk alone at night".

	N	Mean Rank	Sum of ranks		N	Mean Rank	Sum of ranks
Group 1				Group 2			
Walk alone at night (day vs. after dark)							
Negative Ranks	71	78.01	5539.00	Negative Ranks	95	94.24	8953.00
Positive Ranks	84	77.99	6551.00	Positive Ranks	91	92.73	8438.00
Ties	85			Ties	118		
Total	240			Total	304		
Walk alone at night vs. walk alone (daytime)							
Negative Ranks	121	74.51	9016.00	Negative Ranks	157	91.96	14438.00
Positive Ranks	20	49.75	995.00	Positive Ranks	23	80.52	1852.00

Ties	99			Ties	124		
Total	240			Total	304		
Walk alone at night vs. walk alone (after-dark)							
Negative Ranks	78	64.40	5023.00	Negative Ranks	93	75.46	7018.00
Positive Ranks	47	60.68	2852.00	Positive Ranks	47	60.68	2852.00
Ties	115			Ties	164		
Total	240			Total	304		

Considering the comparison between day and after-dark items of walking alone at night, which is a similar item to the one examined in field study 1 (section 6.2.1.), negative ranks stand for lower scores in daytime, positive ranks for higher scores in daytime and ties for equal scores. Group 1, starting the field study in daytime, present seventy-one lower ratings in daytime compared to after-dark, thus indicating that locations were imagined to be less reassuring than when experiencing it, but eighty-four ratings were higher in daytime and eighty-five similar ratings independent of time-of-day. For Group 2, starting after-dark, 118 ratings were similar in both conditions, while 95 scores were higher in after-dark and 91 higher in daytime. Thus, participants experiencing the location after-dark seem to recall it differently, either more or less reassuring.

However, the Wilcoxon signed-rank test result showed that there was no significant difference between the assessment of risk of walking alone at night for daytime and after dark in group 2 (Z= -0.364, p = 0.716) and in group 1 (Z= -0.941, p = 0.347). Overall, participants from field study 2 presented a higher number of tied ratings, which can also indicate familiarity with the locations or area.

For the established comparisons between the survey items “walk alone” and “walk alone at night” negative ranks indicate lower scores while positive ranks indicate higher scores in the walk alone at night item. When comparing the results from the two survey items (walk alone versus walk alone at night) in daytime the Wilcoxon signed-rank test statistics show significant differences in ratings for group 1 (Z = -8.521, p < 0.001) and group 2 1 (Z = -9.318, p < 0.001) suggesting participants read and interpreted the items differently. The same is verified if a comparison of scores after-dark is considered (Z = -2. 910, p = 0.004 for group 1 and Z = -4.576, p < 0.001 for group 2). The after-dark ratings would be expected to present similar results, however this significantly different evaluation in both items could imply that participants understood that the walk alone question related to an overall circumstance, rather than specifically at night as the other item indicated.

6.3. Real versus perceived lighting

During field studies 1 and 2, five lighting-related items were added to the after-dark version of the questionnaire (section 4.2.4. and 5.2.3.). These items asked participants to rate road lighting with regards to the (1) road lighting quality, (2) brightness, (3) glare, (4) apparent spatial distribution (referred as uniformity in this section) and (5) overall satisfaction. Figure 27 displays the items and the response rating scale.

Figure 27. Five lighting items used in after dark questionnaire version in field study 1 and 2.

The lighting on this street is:	Bad	1	2	3	4	5	6	Good
	Bright	1	2	3	4	5	6	Dark
	Not glaring	1	2	3	4	5	6	Glaring
	Unevenly spread (patchy)	1	2	3	4	5	6	Evenly spread (uniform)
Overall, how satisfied are you with the lighting on this street?	Very dissatisfied	1	2	3	4	5	6	Very satisfied

Responses to the five items in field study 1 and 2 are examined in this section. The data is explored to confirm or infirm three premises:

1. Subjective evaluations of road lighting are significantly associated with lighting measurements.
2. The association of subjective evaluations of lighting and illuminances shows a range bias.
3. Lighting subjective evaluations are significantly associated with the reassurance composite rating.

Brightness and Glare scores were reversed so higher scores to every item correspond to satisfaction with road lighting appraisals. Field study 1 had twenty-four participants answering in each location, thus providing a total of 240 responses (section 4.2.3). One participant did not answer to the glare item on one location. On the other hand, during field study 2, thirty-four participants responded to these items in 16 locations, providing 544 responses (section 5.2.3). Five responses were coded as missing (1 quality, 1 brightness, 3 glare). The Shapiro-Wilks test was applied to check for data normality showing that data was not normally distributed in field study 1 and 2 ($p < 0.5$).

6.3.1. Field study 1

The degree of association between the subjective evaluations of lighting was examined considering the spearman's rank (two-tailed). The closer to 1 the correlation coefficient is, the higher the association between variables. Associations are significant at $p \leqslant 0.05$. Table 37 shows the correlations between the five item responses (N=240).

Table 37. Degree of correlation among the subjective lighting items.

Variable	Brightness		Glare		Uniformity		Satisfaction	
	R	p	R	p	R	p	R	p
Quality	0.63	<0.001	-0.157	0.015	0.67	<0.001	0.85	<0.001
Brightness	-	-	-0.007	0.917	0.53	<0.001	0.60	<0.001
Glare	-	-	-	-	-0.05	0.437	-0.114	0.077
Uniformity	-	-	-	-	-	-	0.67	<0.001

The assessments are mostly significantly associated, except for the variable "glare", which displayed a mostly non-significant inverse correlation with the remaining four variables. This suggests that participants associated highest rated glare with satisfying lighting conditions. There are two potential explanations: (1) unfamiliarity with the term "glare" or (2) "glare" is perceived as promoting brightness, thus somehow representing higher lighting quality (quality vs. glare R = -0.157, p=0.015). The remaining four variables were significantly associated.

Ratings were averaged per road for each variable. Table 38 shows the averaged ratings for each variable per road. Ratings were recorded in a 6-point rating score, where the highest score means a good evaluation of lighting (good, bright, not glary, uniform lighting and satisfied with lighting).

Table 38. Subjective lighting appraisals averaged per road.

Road	Light Quality	Light Brightness	Light Glare	Light Uniformity	Light Satisfaction
1	3.00	3.21	4.29	2.83	2.96
2	2.25	2.50	4.17	2.71	2.42
3	4.13	3.58	4.38	3.88	4.17
4	4.17	4.00	4.17	3.58	4.13
5	4.17	3.79	4.04	3.58	4.29
6	4.92	4.08	4.08	4.38	4.92
7	3.96	3.71	3.83	3.50	3.88
8	3.21	2.96	4.38	2.83	3.17
9	2.83	2.71	4.75	3.54	3.25
10	5.88	5.04	3.54	5.83	5.63

The association between the averaged scores (quality, brightness, glare, uniformity, and overall satisfaction) and horizontal illuminances and the reassurance composite rating were examined. In previous studies the lighting perceived as the brightest has been reported as safer (Knight 2010), so brightness would be expected to correlate with light quality and satisfaction. The Spearman's rho and significance are reported in Table 39. Due to the difference in urbanistic nature of the park footpath and the underpass (R9 and R10), the analyses are presented for N=10 and N=8.

Table 39. Degree of correlation between illuminance metrics and the questionnaire items evaluating lighting.

Illuminance	Light Quality		Light Brightness		Light Glare		Light Uniformity		Light Satisfaction	
N=10	R	p	R	p	R	p	R	p	R	p
Mean	0.23	0.0532	0.16	0.651	-0.19	0.609	0.42	0.233	0.33	0.347
Minimum	0.63	0.05	0.58	0.082	-0.63	0.052	0.54	0.110	0.61	0.06
Uniformity	0.66	0.037	0.59	0.074	-0.57	0.087	0.58	0.079	0.66	0.038
N=8										
Mean	0.11	0.799	0.00	1	-0.012	0.977	0.17	0.690	0.12	0.779
Minimum	0.44	0.272	0.357	0.385	-0.34	0.414	0.31	0.450	0.41	0.320
Uniformity	0.54	0.168	0.43	0.289	-0.27	0.526	0.46	0.254	0.52	0.183

Table 39 shows that there is a low degree of significant association between the subjective evaluations of lighting and the actual lighting. The only significant correlations are of horizontal minimum illuminance with the quality of lighting (R = 0.63, p = 0.05) and glare (R = -0.63, p = 0.052), and uniformity illuminance with light quality (R = 0.66, p= 0.037) and overall satisfaction (R = 0.66, p = 0.038) for N=10. The location R10 offers high horizontal minimum illuminance (section 4.2.2), thus likely influencing correlations. However, results show that the relationship between minimum horizontal illuminance and light quality is inverse to the association with glare. This seems to be consistent with results from correlations between the subjective evaluations of lighting (Table 37), where glare seems to be perceived as a positive attribute to road lighting. Figures 28 to 30 show the five subjective lighting assessments plotted against horizontal mean and minimum illuminance and illuminance uniformity for N=10, and Figures 31 to 33 for N=8. This was done using a linear function, as this was the best fit.

Figure 28. Lighting ratings of glare, quality, brightness, uniformity and satisfaction plotted against mean horizontal illuminances for N=10.

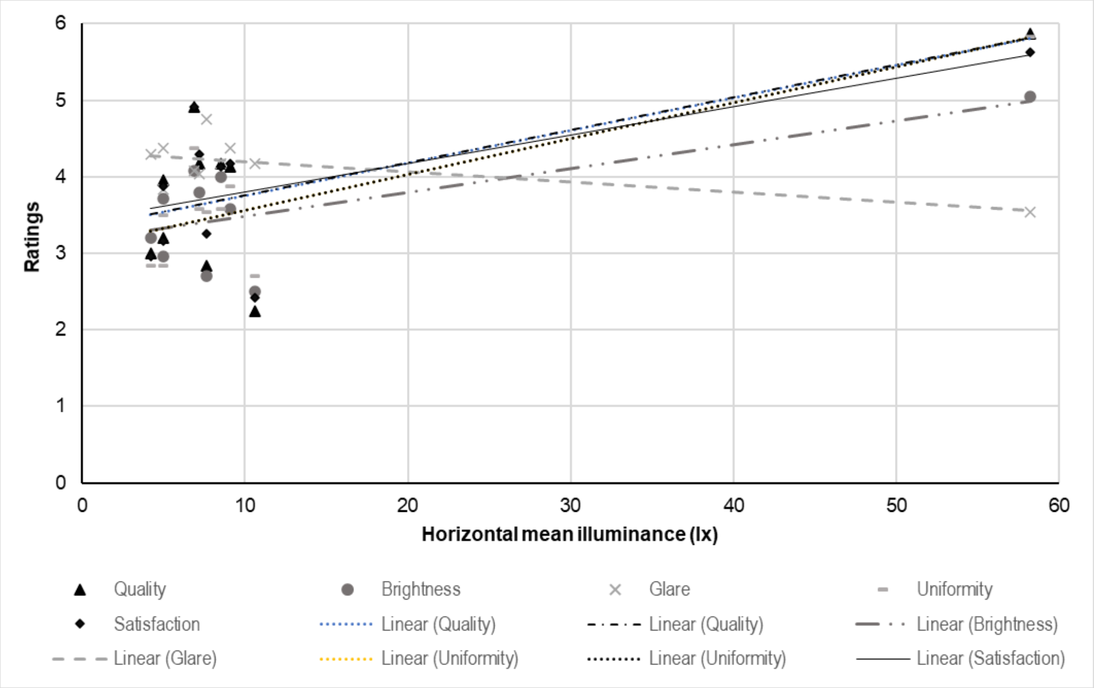


Figure 29. Lighting ratings of glare, quality, brightness, uniformity and satisfaction plotted against minimum horizontal illuminances for N=10.

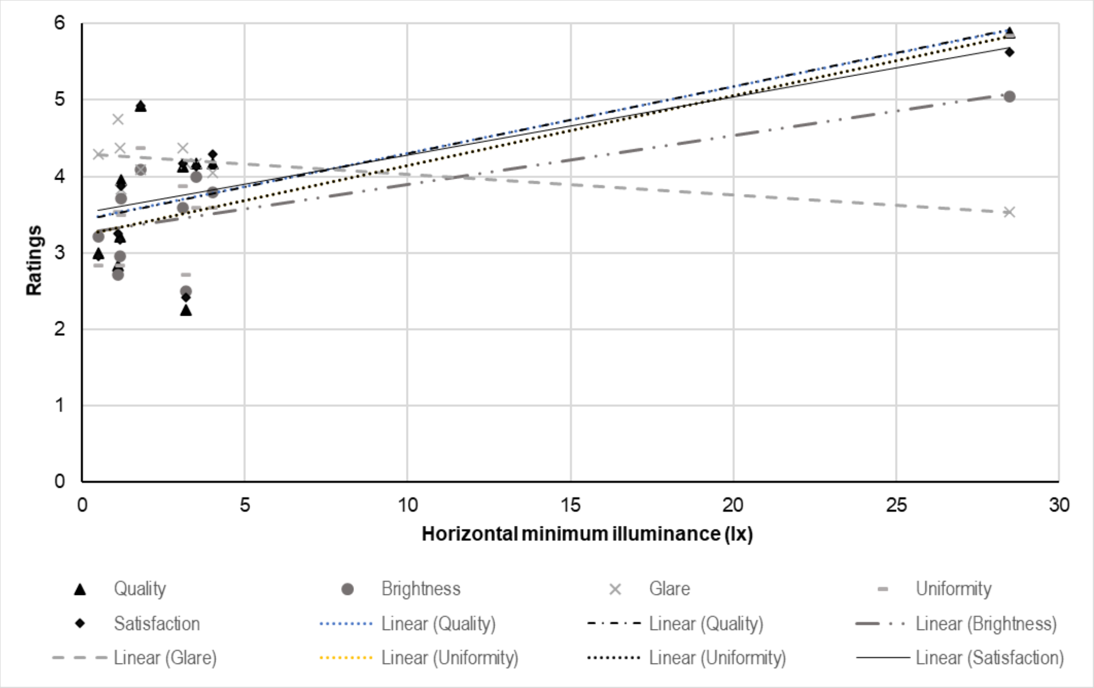
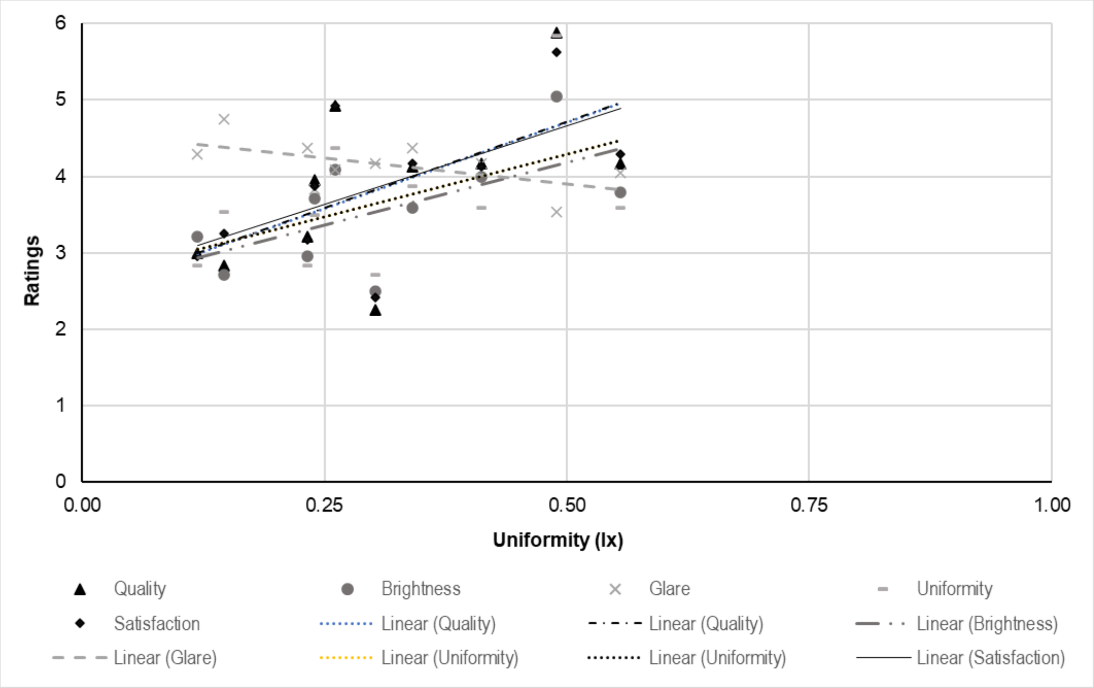


Figure 30. Lighting ratings of glare, quality, brightness, uniformity, and satisfaction plotted against uniformity illuminances for N=10.



Figures 28 to 30 seem to suggest that the evaluations present a range bias for N=10. Thus, the highest mean and minimum illuminances being rated as the ones with the highest uniformity, brightness, quality and promoting more satisfaction with the road lighting. The underpass provides an extreme illuminance value that outlies the normality of the lighting data, generating an averaged rating close to 6.

Figure 31. Lighting ratings of glare, quality, brightness, uniformity and satisfaction plotted against mean horizontal illuminances for N=8.

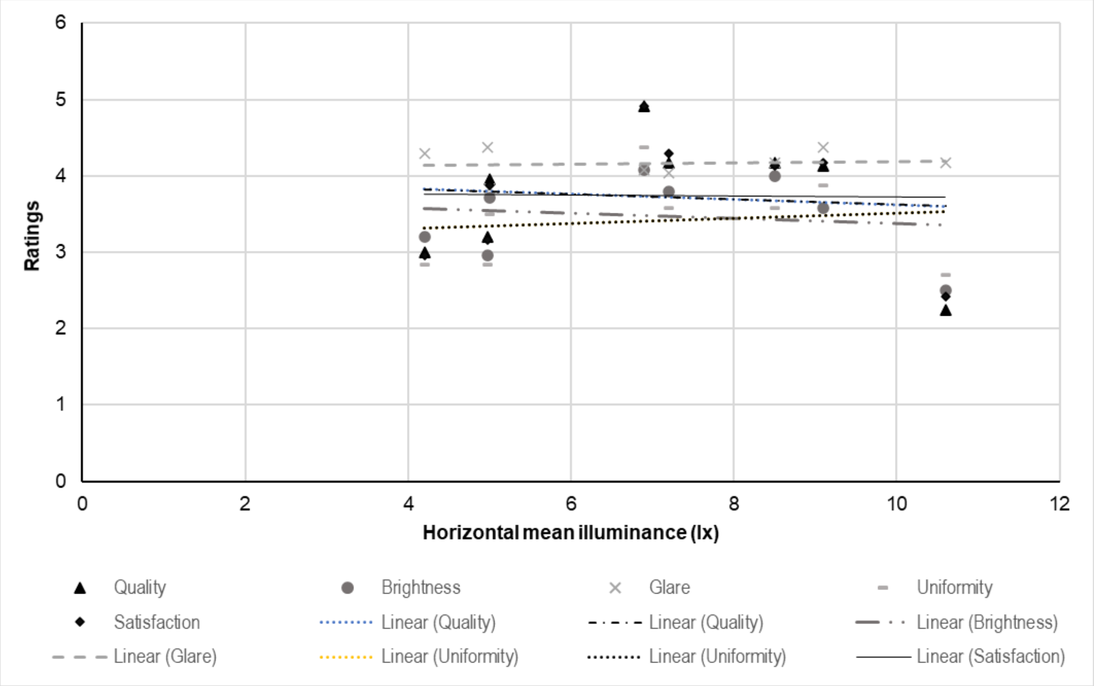


Figure 32. Lighting ratings of glare, quality, brightness, uniformity and satisfaction plotted against minimum horizontal illuminances for N=8.

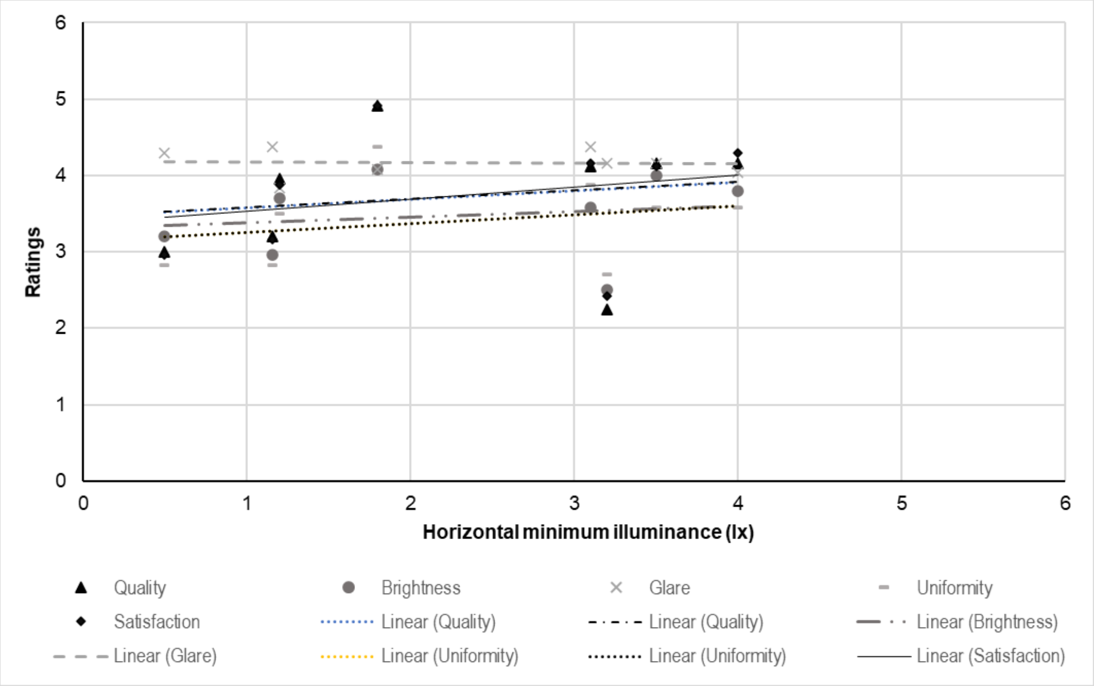
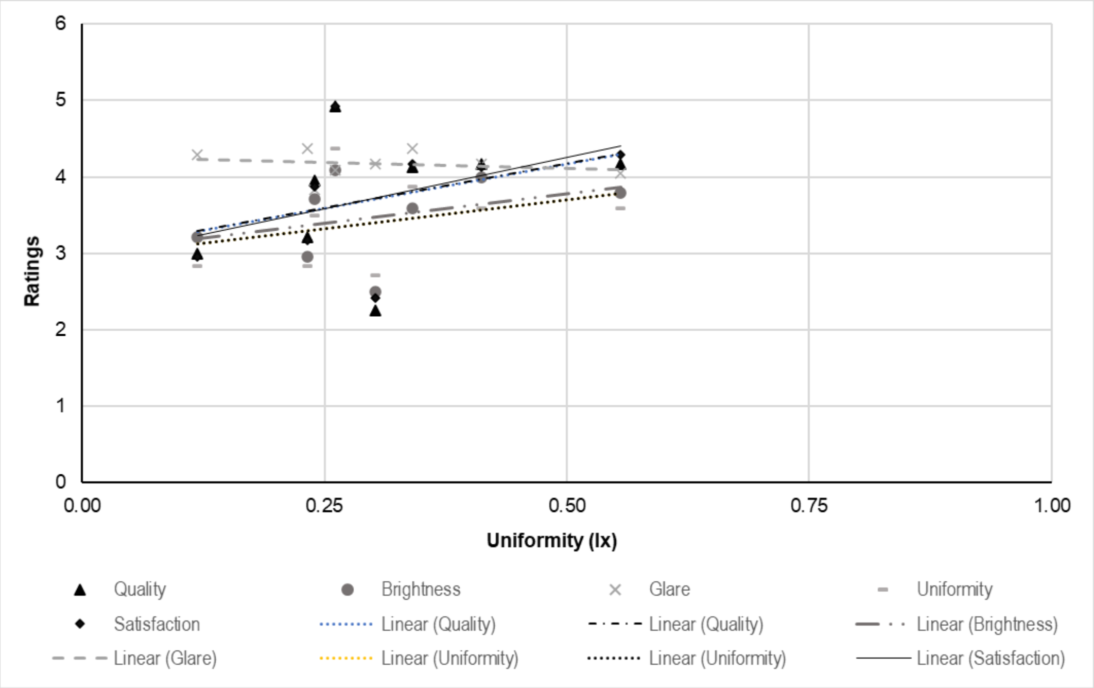


Figure 33. Lighting ratings of glare, quality, brightness, uniformity and satisfaction plotted against minimum horizontal illuminances for N=8.



When only 8 locations are considered, the rating of lighting seems to be quite similar independently of the mean horizontal illuminance in the location (Figure 31). Ratings seem to increase slightly from a score of approximately 3 to a score of 4, in a 6-point rating scale, as minimum horizontal illuminance rises (Figure 32). The association of ratings and uniformity seem to display the same trend (Figure 33). However, the data points do not show a determining range bias.

Correlations between the lighting-related items and the reassurance composite score are reported in Table 40 using the Spearman's rank.

Table 40. Degree of correlation between the questionnaire items evaluating lighting and the reassurance composite for N=10 and N=8.

Variable	Quality		Brightness		Glare		Uniformity		Satisfaction	
	R	p	R	p	R	p	R	p	R	p
N=10										
Composite	-0.57	0.084	-0.48	0.162	0.48	0.159	-0.46	0.177	-0.54	0.108
N=8										
Composite	-0.30	0.471	-0.14	0.736	0.05	0.910	-0.19	0.647	-0.29	0.493

Results show no significant correlations (p > 0.5) between the five subjective assessments and the reassurance composite for both N=10 and N=8. Figures 34 and 35 display the linear association between these items.

Figure 34. Lighting ratings of glare, quality, brightness, uniformity and satisfaction plotted against the reassurance composite rating N=10.

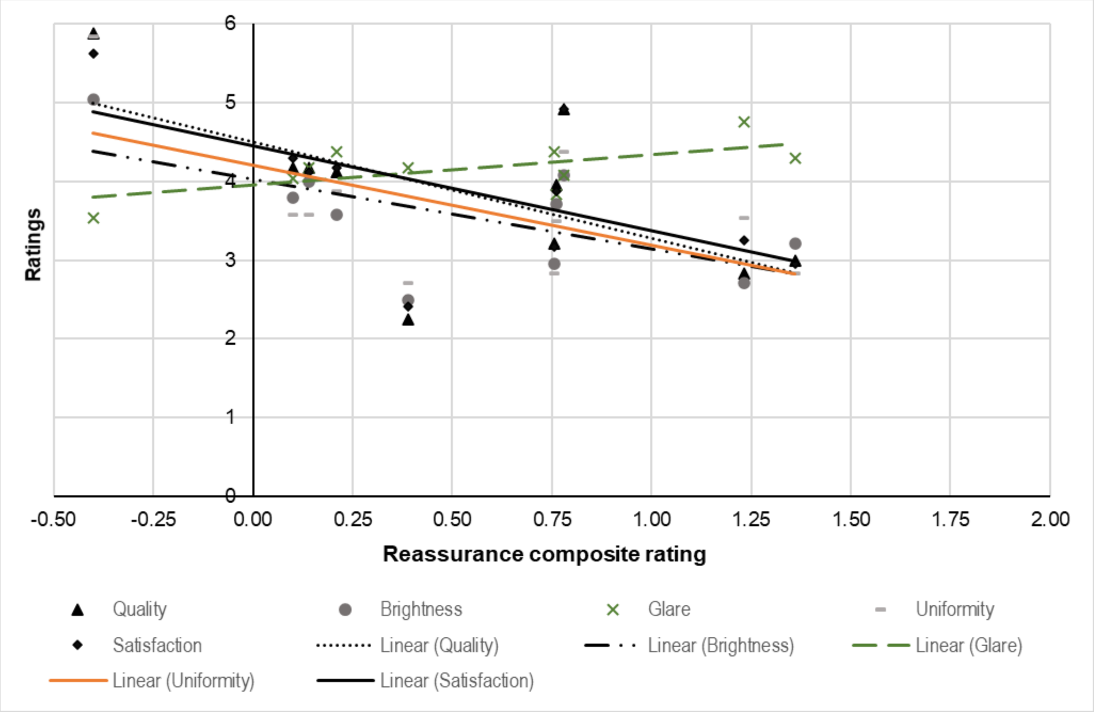


Figure 35. Lighting ratings of glare, quality, brightness, uniformity and satisfaction plotted against the reassurance composite rating N=8.

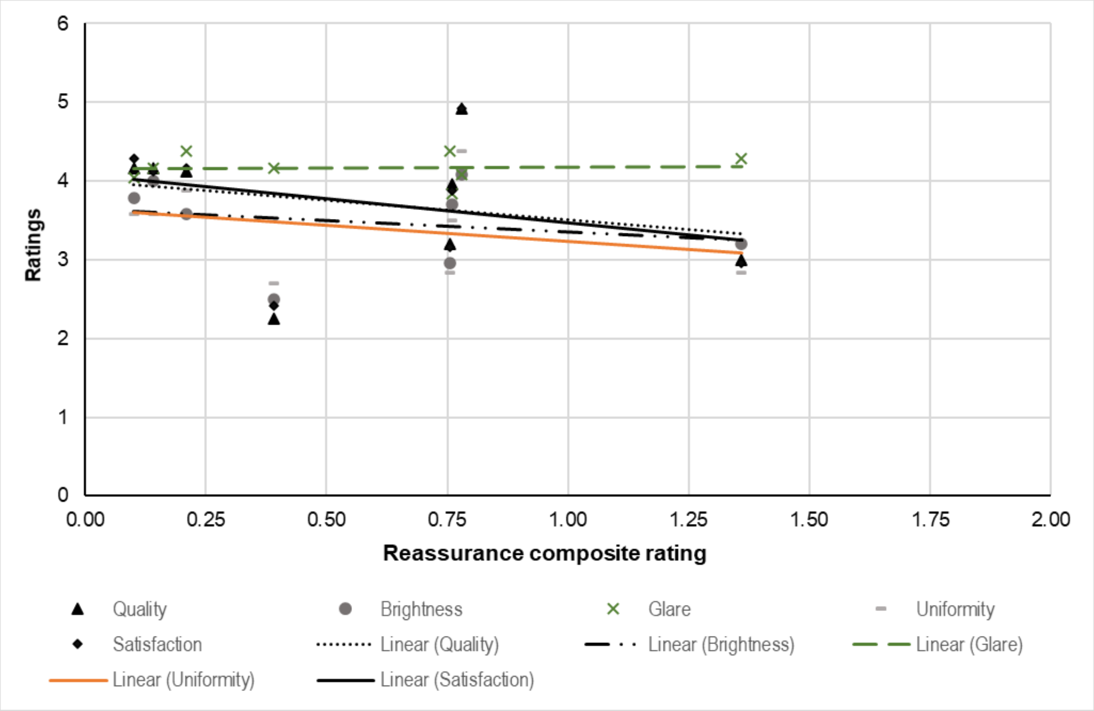


Figure 34 suggests that increased glare scores associate with higher reassurance, while the highest the scored quality, brightness, uniformity, and satisfaction with the road lighting associates with higher perceived safety.

6.3.2. Field study 2

Similarly, to section 6.3.1., the degree of association between subjective assessments on lighting were examined using Spearman’s rank. The correlations between the five lighting-related survey items were investigated considering N=544.

Table 41. Degree of correlation among the subjective lighting items.

Variable	Brightness		Glare		Uniformity		Satisfaction	
	R	p	R	p	R	p	R	p
Quality	0.54	<0.001	-0.27	<0.001	0.64	<0.001	0.86	<0.001
Brightness	-	-	-0.10	0.023	0.45	<0.001	0.50	<0.001
Glare	-	-	-	-	-0.19	<0.001	-0.26	<0.001
Uniformity	-	-	-	-	-	-	0.68	<0.001

The ratings evidence a high degree of association at a significant level, except the variable glare. Comparably to field study 1, glare displays a moderate negative correlation with the remaining variables (quality, brightness, uniformity, and satisfaction), however significant ($p < 0.03$). Thus, indicating that participants would expect good lighting to be glarier.

Each participant rated each location resulting in a total of 34 scores per road; these were averaged per road (Table 42) to allow an examination of the degree of association with illuminances and the reassurance composite (Table 43).

Table 42. Subjective lighting appraisals averaged per road.

Road	Light Quality	Light Brightness	Light Glare	Light Uniformity	Light Satisfaction
1	2.65	2.76	4.44	2.32	2.47
2	4.06	3.76	4.15	3.82	4.03

3	4.09	3.82	4.00	3.97	3.97
4	3.85	3.56	4.15	3.62	3.82
5	4.56	4.18	3.47	4.56	4.50
6	3.94	3.65	4.12	3.56	3.79
7	2.12	2.12	4.79	2.29	2.24
8	4.47	4.03	3.71	4.12	4.47
9	4.44	3.82	3.85	4.09	4.38
10	3.71	3.65	3.91	3.62	3.41
11	4.35	3.76	3.65	3.88	4.15
12	4.21	3.97	3.94	3.79	3.94
13	3.68	3.41	3.94	3.56	3.50
14	3.38	3.53	4.15	3.56	3.53
15	2.62	3.85	4.53	2.50	2.82
16	3.62	3.53	3.71	3.26	3.71

Table 43. Degree of correlation between illuminance metrics and the questionnaire items evaluating lighting.

Illuminance	**Light Quality**		**Light Brightness**		**Light Glare**		**Light Uniformity**		**Light Satisfaction**	
Horizontal	**R**	**p**	**R**	**p**	**R**	**p**	**R**	**p**	**R**	**p**
Mean	0.40	0.122	0.15	0.571	-0.18	0.508	0.46	0.073	0.45	0.083
Minimum	0.61	0.012	0.46	0.073	-0.52	0.038	0.63	0.010	0.64	0.008
Uniformity	0.33	0.217	0.19	0.473	-0.32	0.235	0.33	0.218	0.33	0.208
Hemispherical										
Mean	0.60	0.013	.0.41	0.110	-0.37	0.163	0.67	0.004	0.64	0.008
Minimum	0.50	0.050	0.38	0.143	-0.41	0.111	0.53	0.037	0.52	0.041
Semi-cylindrical										
Mean	0.52	0.037	0.40	0.127	-0.30	0.252	0.61	0.012	0.59	0.016
Minimum	0.67	0.004	0.45	0.079	-0.48	0.061	0.67	0.004	0.70	0.003

Table 43 shows that the items light quality, uniformity, and satisfaction correlate significantly with the horizontal minimum, hemispherical mean and minimum, and semi-cylindrical mean and minimum illuminances. These results seem to confirm results from chapter 5 (section 5.3.2. and 5.3.3) that indicate that hemispherical and semi-cylindrical illuminances are also relevant to reassure pedestrians after-dark. Minimum horizontal illuminance is not only significantly correlated with light quality, uniformity, and satisfaction, but also with glare (R= -0.52, p= 0.038). Although this is the only significant association of glare with the lighting metrics, it is important to note that all correlations are inverse. Confirming results from section 6.3.1. and reinforcing the idea that glare is perceived by participants as an aspect of good lighting. Figures 36 to 40 show the graphical representation of the association of the significant correlations, using a linear function. Figure 36 to 38 display the association between the averaged ratings of light quality, brightness, glare, uniformity, and satisfaction with the horizontal, hemispherical and semi-cylindrical illuminances minima. Figure 39 and 40 display the association between the lighting subjective appraisals and the hemispherical and semi-cylindrical mean illuminances.

Figure 36. Lighting ratings of glare, quality, brightness, uniformity and satisfaction plotted against minimum horizontal illuminances for N=16.

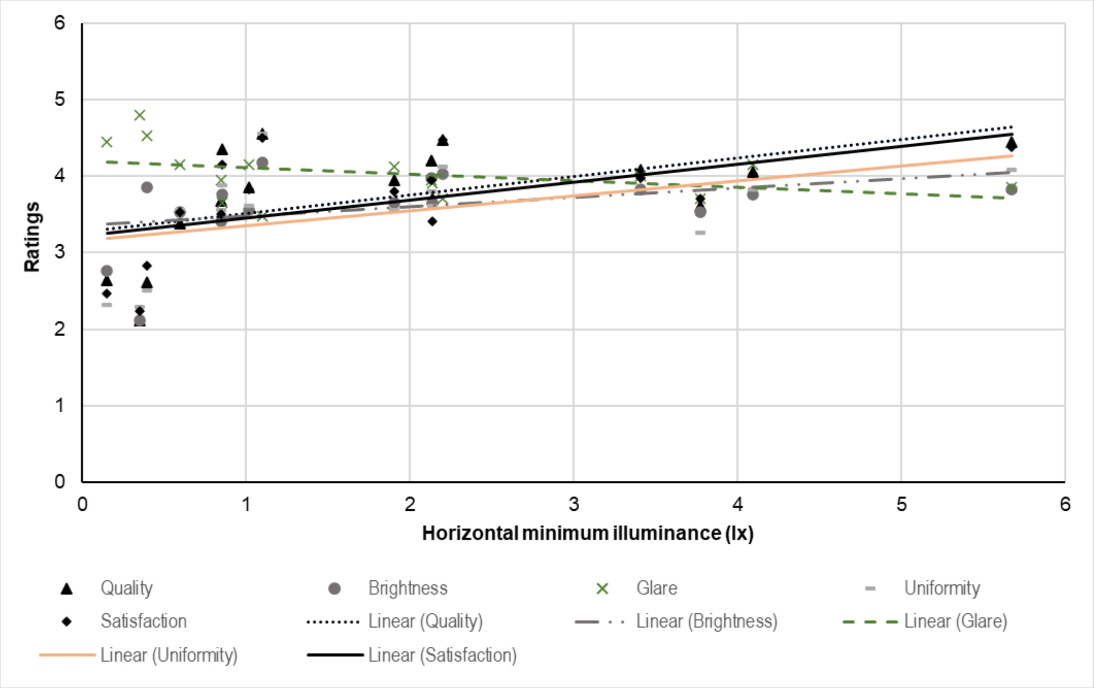


Figure 31 shows that over 2 lux of horizontal minimum illuminance produces an appraisal of lighting quality of 4 to 4.5 unit, in a 6-point rating scale. This agrees with the proposals from chapter 5 discussion (section 5.4.) that a minimum horizontal around 2 lux meets pedestrian needs.

Figure 37. Lighting ratings of glare, quality, brightness, uniformity and satisfaction plotted against minimum hemispherical illuminances for N=16.

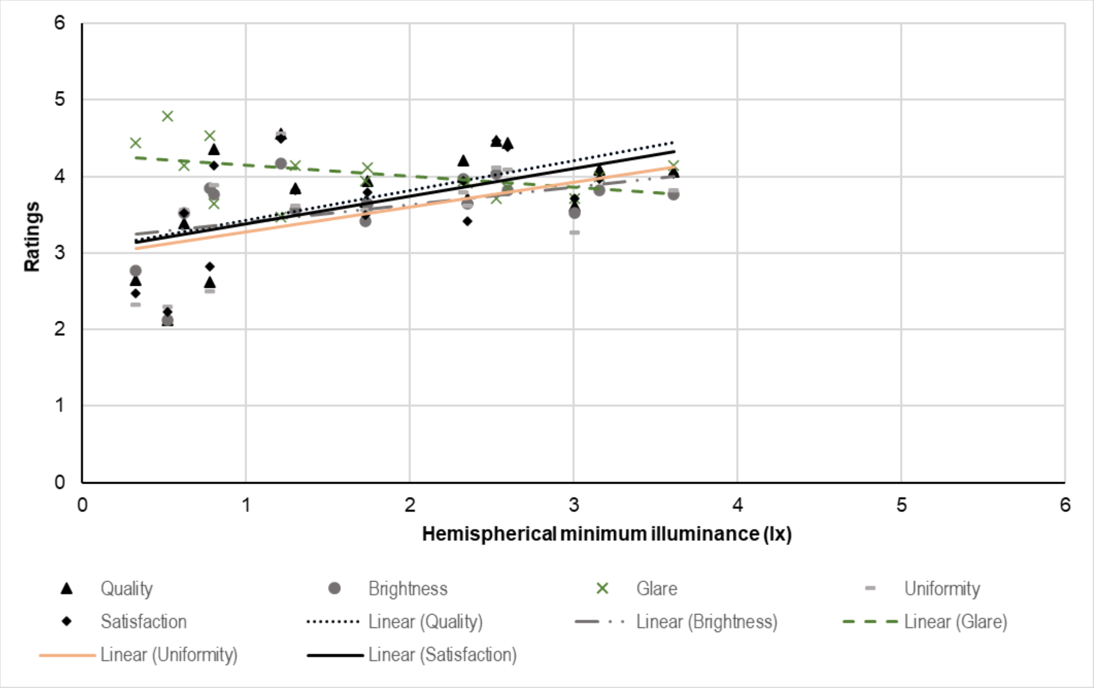


Figure 38. Lighting ratings of glare, quality, brightness, uniformity and satisfaction plotted against minimum semi-cylindrical illuminances for N=16.

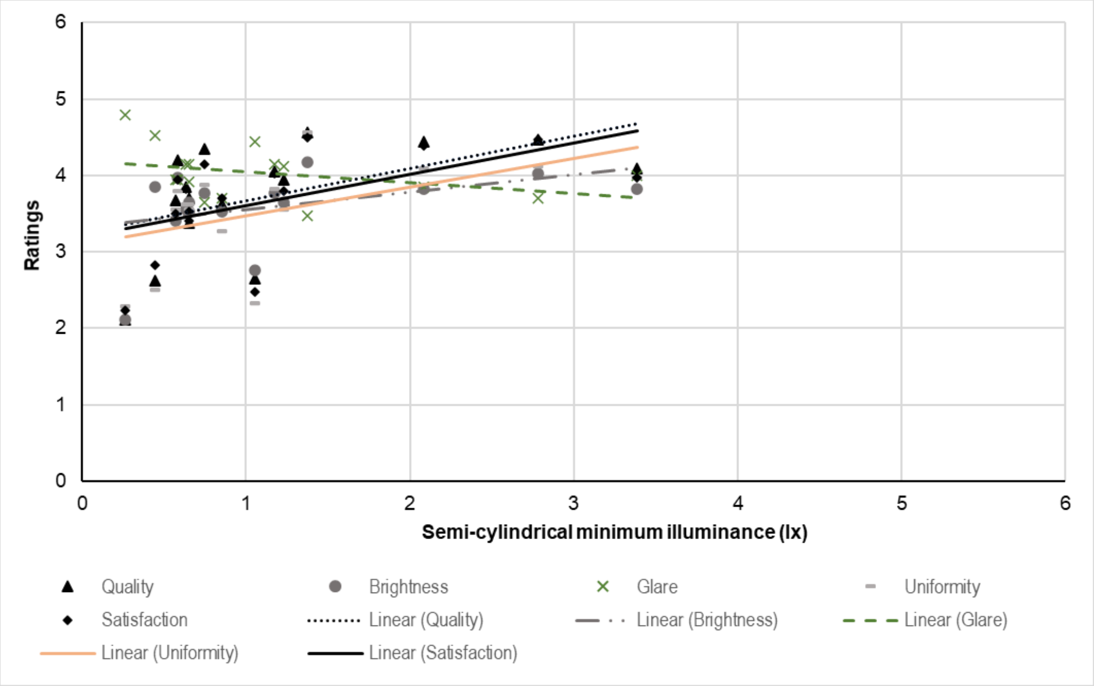


Figure 39. Lighting ratings of glare, quality, brightness, uniformity and satisfaction plotted against mean hemispherical illuminances for N=16.

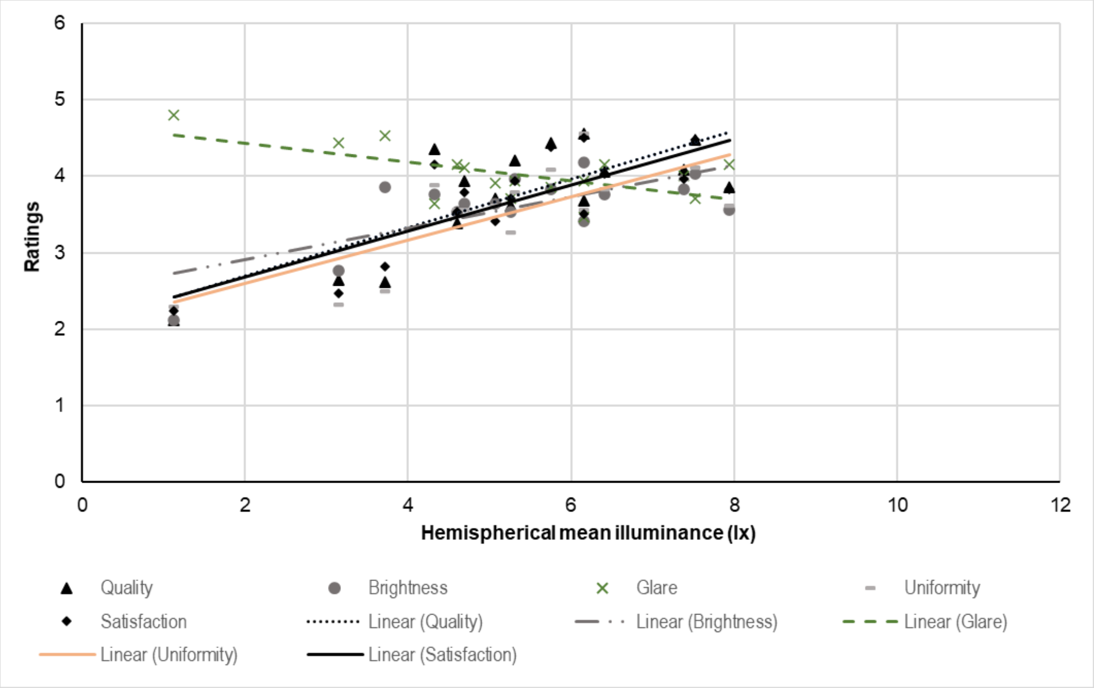
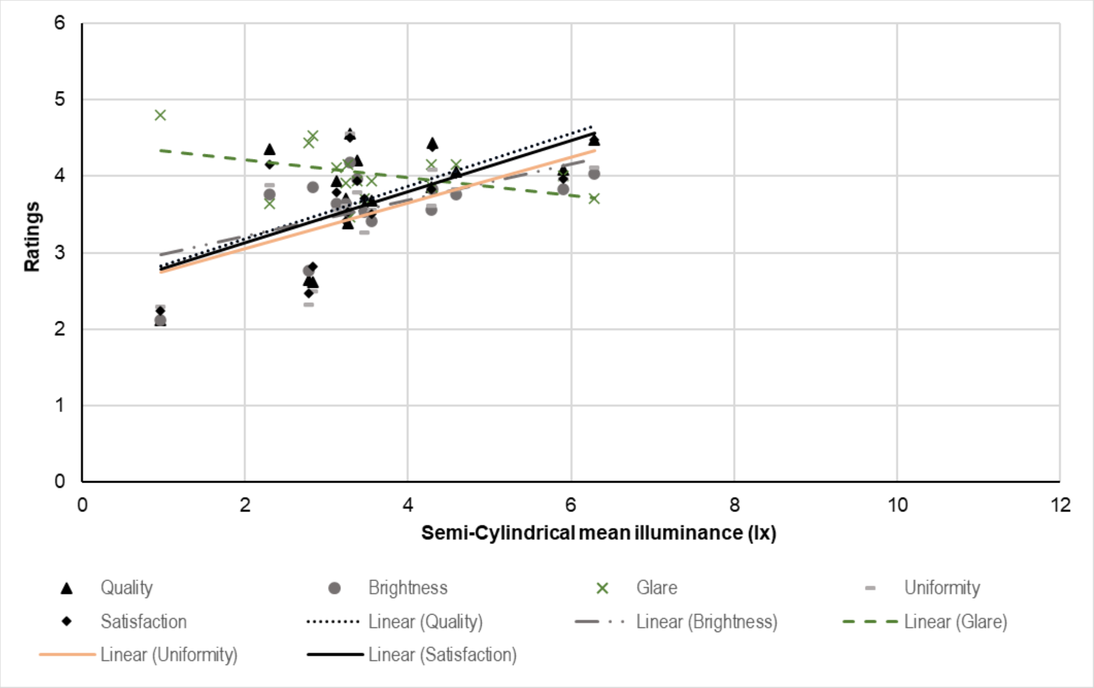


Figure 40. Lighting ratings of glare, quality, brightness, uniformity and satisfaction plotted against mean semi-cylindrical illuminances for N=16.



The trendline in Figures 36 to 40 show that a slight growth is visible in lighting evaluations of quality, brightness, uniformity and satisfaction as illuminance increases.

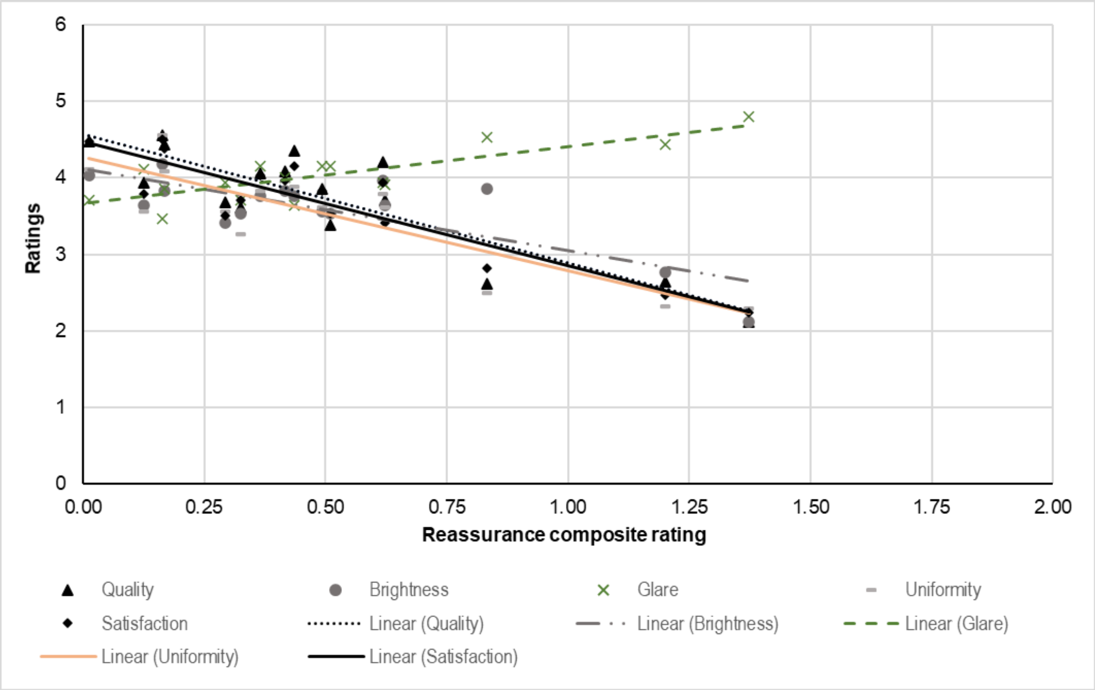
However, it is also observable that distinct ratings are produced for the same lighting levels frequently. After 4 lux of hemispherical mean illuminance, most scores are agglomerated around 3.25 and 4.5 units, in a 6-point rating scale (Figure 39). While for semi-cylindrical mean illuminance scores after approximately 2.3 lux, ratings seem to cluster between 3.25 to 4.70 units in a 6-point rating scale (Figure 40). Table 44 shows the associations between the reassurance composite and these five items.

Table 44. Degree of correlation between the questionnaire items evaluating lighting and the reassurance composite for N=16.

Variable	**Quality**		**Brightness**		**Glare**		**Uniformity**		**Satisfaction**	
	R	**p**	**R**	**p**	**R**	**p**	**R**	**p**	**R**	**p**
N=16										
Composite	-0.69	0.003	-0.42	0.104	0.65	0.007	-0.63	0.009	-0.73	0.001

The reassurance composite rating displays a high and significant level of association with the quality (R=-0.69, p = 0.003), glare (R=0.65, p=0.007), uniformity (R=-0.63, p=0.009) and satisfaction of lighting (R=-0.73, p=0.001). Except for glare, the remaining variables are negatively correlated to the reassurance composite, confirming the registered trend in field study 1 (section 6.3.1). Figure 41 shows the linear association between the five lighting scores and the composite rating.

Figure 41. Lighting ratings of glare, quality, brightness, uniformity and satisfaction plotted against the reassurance composite rating N=16.



6.4. Discussion

This chapter surveyed the sustainability of using subjective assessments to evaluate after-dark settings. This was done in two sections: (1) the examination of evaluations of an imagined or recalled after dark scenario (section 6.2.) and (2) the analysis of the association of subjective appraisals of lighting with actual lighting levels and the reassurance composite rating (section 6.3.).

Perceptions are individual and dependant on individual experiences that create an internal model that serves as a comparison for every other experience (Canter, 1977). Thus, spaces are represented internally in a different way between individuals. This is particularly relevant for the study of pedestrian reassurance. Diverse safety and lighting studies relied on the evaluations of pictures to evaluate lighting, or over-the-phone interviews to evaluate how fearful an individual felt after-dark when walking outside (van Rijswijk, Rooks & Haans, 2016; Boomsma & Steg, 2014). However, some studies show that perceptions change over time, and the internalised perceptual models could provide fraudulent appraisals (Michelian 2016). The purpose of this cognitive mechanism is human survival, allowing individuals to read and interpret environmental cues, for example being at risk.

An item was included in field study 1 and 2 that asked in the daytime and after dark about how risky the participant thought it would be to walk alone at night in each location. Asking such an item requires either imagining or recalling the level of safety in a location or area in the daytime. This is identified as a potentially critical issue (see section 3.2.) because evaluations can be divergent depending on whether the individual is experiencing the environment in the real world or through other means (Bishop & Rohrmann 2003).

Field study 1 results confirmed a significant discrepancy between ratings in daytime and in after-dark (group 1: $Z = -3.580$, $p < 000.1$, and group 2: $Z = -2.499$, $p = 0.012$). Excluding participants that ranked locations similarly in that item, participants who had to evaluate the potential risk through imagining the location after-dark mostly provided higher reassurance in the daytime than after-dark. An effect is also observable for the group of participants who started after-dark. When recalling the darkness, during the daytime, locations tended to be rated as less reassuring. These results seem to confirm studies that found that evaluations by memory tend to be weaker than the original experience (Uchikawa & Ikeda 1986), and also that the phrasing exists as a representation of knowledge or induced experience (Heit 1997;

Fairlough 2003). Thus, nighttime could be associated with the representation of riskier contexts, and thus perceived and evaluated as such.

In Field study 2, an item that did not use the phrasing “at night” was included in the questionnaire. Results of comparisons between ratings to both items in the day and after dark show that participants read carefully the items producing distinct responses to the level of perceived risk in that moment or after dark (daytime ratings of group 1: Z = -8.521, p < 0.001, and of group 2: Z = -9.318, p < 0.001). Although responses in the after-dark condition were expected to be alike for both items, these were not so (group 1: Z = -2. 910, p = 0.004 and group 2: Z = -4.576, p < 0.001). Field study 2 included similar items, so it could have led participants to understand the item that did not include the at-night phrasing as regarding either daytime or an overall evaluation. In hindsight, the item could have been phrased in a clearer manner, by including “during this time of the day”, for example. Interestingly, results from the comparison between scores to the item that used the phrasing “at night” in daytime and after-dark were not significant. There is a possibility that these participants were more familiar with the area and thus already had a stronger internalised model with regard to the area where the field study took place. It is important to note that the Netherthorpe area is near the University campus, which should be familiar to the participants, as students. This possibility is likely as tied results in field study 2 were very high.

Although results are not conclusive, as field study 2 does not provide a significant difference among the “walk alone at night” rating, results from field study 1 show that not only might there be an effect of memory and imagination in appraisals, but also this effect is distinct. Memory tends to provide more cautionary evaluations, while imagination seems to provide more hopeful scores.

Criminology-oriented studies focused on the assessment of fear of crime frequently use questions to specifically assess reassurance outdoors after-dark (Knight 2010; Boessen et al. 2017). This methodological issue could explain contradictory results in research. The impact of memory and imagination in safety and lighting studies is likely to be of benefit to methodologically account for in further research.

Even though the proposal that the study of the perceived reality (Appleton, 1975; Canter, 1977) is interesting, in the case of lighting-focused studies it seems that it could elicit more difficulties than benefits. Analyses from section 6.3. show that subjective assessments, even *in loco*, are not consistent with the observed effects of actual metrics. It can be argued that this could be because reassurance is influenced by other aspects rather than lighting. However, having applied the day-dark approach (Boyce et al. 2000) should account for other elements present in the urban landscape.

Also, the recorded subjective evaluations did not seem to significantly correlate as expected.

Five items were added to the after-dark questionnaire version in field study 1 and 2. Responding to "*The lighting on this street is..*" there were four semantic differential rating scales: bad-good, bright-dark, glaring-not glaring and, unevenly spread (patchy)-evenly spread (uniform). Also, a final question asked "*Overall, how satisfied are you with the lighting on this street?*" with a very dissatisfied-very satisfied response scale. Recorded responses were highly associated with themselves, but the variable glare showed a negative correlation to the remaining four. This was verified in both studies, suggesting that participants might interpret glare as a positive aspect to lighting, similar to brightness. This is supported by the interaction between glare and higher lighting quality (quality vs. glare R = -0.157, p=0.015). However, it is likely that participants were not acquainted with the terminology, thus providing unusual appraisals.

Field study 1 analyses attended to the association for N=10 and N=8. Unsurprisingly, results vary if the park footpath and the underpass are included. Between the five items, only the quality of lighting (R = 0.63, p = 0.05) and glare (R = -0.63, p = 0.052) associate with horizontal minimum illuminance, and light quality (R = 0.66, p= 0.037) and overall satisfaction (R = 0.66, p = 0.038) with uniformity illuminance with for N=10. No significant associations are observed for N=8. It is interesting, nevertheless, that the metrics which are relevant for field study 1 – horizontal minimum and uniformity illuminance (chapter 4), display some level of influence in the perceived quality of lighting, however, not associating with the reassurance composite for both N=10 and N=8. When considering the ten locations, some level of range bias is identifiable, but if only the ratings from 8 locations are considered, there is no clustering depending on the higher illuminance. The lighting levels provided by the location R10 are uncommonly high (section 4.2.2), thus likely influencing the trendline and degree of association between metrics and subjective assessments.

Results from field study 2 confirm the inverse association of glare with the remaining four items (quality, brightness, uniformity, and satisfaction), thus reinforcing the idea that good lighting should be glarier. The associations between the subjective assessments and the metrics, also seem to confirm the results from chapter 5, as significant correlations are registered between the items light quality, uniformity, and satisfaction and horizontal minimum, hemispherical mean and minimum, and semi-cylindrical mean and minimum illuminances. It is debated in chapter 5 (section 5.4) that a combination of horizontal minimum illuminance and hemispherical mean illuminance can account better for reassurance. These results seem to suggest that this is true, as the same items present a significant association with the reassurance composite. This is to note that these metrics somehow are related to a higher perceived uniformity. This is interesting as uniformity illuminance did not present as significant in field study 2 (chapter 5), as in field study 1 (chapter 4). It might indicate that more consistent mean hemispherical illuminance accounts for the patchiness in lighting distribution.

Thus, although not every subjective evaluation is significantly associated with lighting, the metrics that proved to be relevant in each study did correlate with at least the evaluation of the quality of the lighting. It is inconclusive if subjective evaluations of lighting produce range bias.

Finally, even though the brightness was expected to associate with reassurance, it did not. These results are contrary to the literature, which suggests that participants report feeling safer depending on the perceived brightness of lighting. It is important to acknowledge that the lighting subjective evaluations are not always significantly associated with the reassurance composite rating. However, the ratings of the overall satisfaction and the quality of lighting did show a significant association for field study 2. Thus, indicating that subjective appraisals can be reasonable if conclusions drawn are considerate of their limitations to advise on quantity or quality of lighting.

6.5. Summary

Chapter 6 focuses on the matter of imagined and perceived illuminance and the potential implications in terms of methodology. Thus, two sections of data were analysed: one focused in the recalling or imagining of illuminance and the other on subjective evaluations of the quality of lighting.

A question from the surveys asked participants to recall or imagine after-dark conditions. Results show that there is a distinction on the level of reassurance reported when the condition is being experienced rather than imagined or recalled through memory of previous experience.

The subjective evaluations of lighting associated with metrics that were demonstrated to be relevant for reassurance in chapter 4 and 5. While brightness did not seem to be relevant for participants to feel reassured, their ratings of satisfaction and quality associated significantly with the reassurance composite.

Chapter 7. Conclusion

The implications of adequate road lighting for the reassurance of its users have been widely studied. However lighting, or the lack of it, seems to have an effect in the safety felt when outside after-dark (Fotios & Unwin 2013), research results are at times discrepant. This can be due to a few methodology-related limitations (chapter 3). On one hand, road lighting is a complex topic of study as it is a single factor integrating a complex urban tissue that continuously emits other stimuli (Appleton 1975; Canter 1977). Thus, isolating the effect of lighting might be challenging. Considering this challenge, this work proposed the application of the day-dark approach (Boyce et al. 2000). This approach assumes that road lighting can only promote the same level of reassurance as felt during the daytime. Comparing the results of only after-dark evaluations and the day-dark difference, the latter helps minimise the range bias.

Another critical issue is that of questionnaire design. Reassurance, fear of crime and perception of safety are recognized as facets to the same construct. Throughout research, these have been studied using different questions and frequently using a single item to measure the level of reassurance. This is critical mainly because any of these aspects occur on a cognitive, emotional and behavioural dimension. Therefore, directing a question to a single dimension and generalising these results can be challenging. For example, an individual might evaluate a context as riskier but not necessarily change their behaviour. From this perspective, a questionnaire was designed to account for the three dimensions on some level and some contextual factors. The ratings were used to build a composite rating, which accounted for all survey items according to their weight. In each study, the PCA generated a clear component of Reassurance, in which the expression of the cognitive, emotional and behavioural dimensions was distinct. Thus, this suggests that a composite rating that attempts at accounting for the complexities of reassurance is good practice.

Nonetheless, it is important to note that the capacity of surveys to measure emotional dimensions is limited. Surveys rely upon self-reporting and thus, might not provide accurate results. Men for example have self-reported to be less fearful than women, which might not be reflecting the truth but a societal understanding that mean should not be fearful. Furthermore, the subjectivity of surveys can also be an issue if representation is considered. Surveys are interpreted by each participant, so it is fundamental to carefully design the questionnaire to reduce the range of interpretation to the meaning of the phrasing. Although the present questionnaire design took this into consideration, it was observable that the merged study of lighting and reassurance requires attention to the slight nuances in text and conditions. The analysis of a question asked to participants with the phrasing “at night” in both daytime and after-dark corroborated not only that phrasing and representation is essential because it might modify results, but also that individuals that must recall and/or imagine after dark conditions are likely to report more fearful than in the actually experienced conditions. This is relevant as it informs survey research moving forward. There is the need to exercise caution when generalising fear of crime results derived from a single item, or an item that is requiring individuals to access memory or to imagine a scenario.

Although this data collection method is widely used in social sciences, it has no doubt recognised limitations (Box, Hale & Andrews 1988; LaGrange & Ferraro 1989; Farrall, Gray & Jackson 2007). Thus, it is appreciated that the study of reassurance and road lighting should explore other methods that could provide more objective assessments. The constant development of technology is making new data collection methods that could be explored in this topic area. For example, through the study of the biological signals of fear of crime or reassurance. Fear is considered a primal emotion that serves a survival purpose. Thus, this emotional state produces a set of physiological reactions that can be measured. Biologically, fear produces several symptoms, such as the increase of the heart frequency, the increase of the sweat in the skin and the constriction of the pupil. There is little research on fear of crime on a biological basis. However, Castro-Toledo et al (2017) have aimed at measuring the physiological indicators of fear, namely heart rate frequency, in a real environment. The variable lighting was controlled; thus, levels of illuminance were altered in order to verify whether this produced any noticeable change in the heart frequency.

Although, Castro-Toledo et al (2017) used a real-life setting, another potential technological development that could facilitate this type of study is the use of simulated environmental conditions through immersed reality. Immersed reality or virtual reality could provide an intermediate setting for the study of road lighting and reassurance. The development of simulated reality or virtual reality in time will make available very similar conditions to the experience of the real world. This potentiates variable control, decreases risks, and might allow the test of a wider sample. A study carried out by Deb et al (2017) proved that virtual reality can be valuable to human factors related research as their results replicated real environments results. However, further progress is needed as 11% of the participants withdrew due to sickness.

Following the considerations on methodology, the lighting-related conclusions are to be mentioned. The specification of optimal illuminance levels aligned with pedestrian needs is important. Energy consumption has a considerable environmental impact, so reducing the waste of energy of road lighting can have a significant impact on the environment and even the economy. As part of a city transport strategy, Sheffield underwent a strategic relighting in several areas. Lighting was indicated as pertinent for enhanced pedestrian safety (Sheffield City Region 2017). If active walking is to be promoted there are a set of aspects that need to be addressed, such as the ability (1) to perform interpersonal judgments at a comfortable distance, (2) to detect obstacles to avoid tripping or falling and (3) to reassure by allowing the visibility of the surroundings. Field study 2, which took place after the relighting, presents roads with low levels of illuminance (e.g., R7). Even though it is unclear which needs were considered to set those lighting installations, this example reiterates the need to align lighting installation levels with its purpose.

Field study 1 and 2 results suggested that a horizontal illuminance between 6.5 to 7.1 lux should be enough to allow pedestrians to feel reassured. Nevertheless, this indication is likely to only work if other lighting levels are accounted for. Minimum horizontal illuminance is the most consistent metric throughout the analyses, suggesting that a minimum of not less than approximately 2 lux is ideal. Moreover, a suggestion of the present work is that road lighting is dynamic, therefore, other metrics should be accounted for, such as hemispherical and semi-cylindrical illuminance. Field study 2 identified that a model considering horizontal minimum and hemispherical mean illuminances could predict best the levels of reassurance reported. Horizontal illuminance tends to be a focus in the scope of road lighting and safety studies but expanding the understanding of the interaction of horizontal illuminance with other illuminances seems to be pertinent for further research.

There are few limitations to the generalisation of field study 1 and 2 results regarding illuminance thresholds. First, this study was carried out in an urban environment in the UK; thus, further validation of these findings should be sought through studies conducted in other locations. This could be done at a suburban, rural, or country level. Also, a varied range of illuminances and metrics should be considered. Then, test participants were recruited within a university context, thus aged between 18 and 38 years. This is important because the visual performance of older people might demand higher levels of lighting, as visual capacity decreases with ageing.

Finally, an important consideration is that as Canter (1977) suggested the study of perceived reality is also useful. The study of the perceived space has been identified as valuable to understand the social implications of the built environment (Canter, 1977) as well as understanding motivations behind rejection or preference of certain space (Appleton, 1975). While it does not provide technical directions, results from chapter 6 (section 6.3) validate that the perceived quality of lighting and overall satisfaction with it is associated with the suggested metrics in previous chapters (chapter 4 and 5).

Interestingly, brightness was expected to be relevant for participants and this was not the case. A common suggestion is that the brighter the light the safer participants report to feel. However, this was not the case. Alternatively, glare seemed to be perceived as good lighting. This could be due to a misunderstanding about the term “glare”, potentially being understood as the quality of brightness.

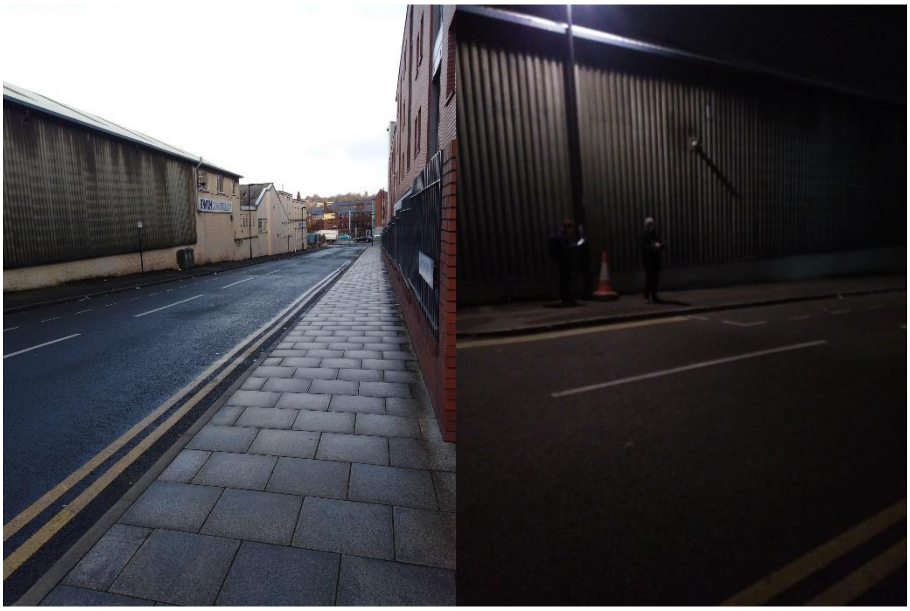
The road network is a complex web of intrinsic needs from different users, such as pedestrians, cyclists, and drivers. Therefore, there is a balance needed when considering the purpose of road usage, users needs and energetic efficiency. Higher illuminance is not always translated into the best user experience. And, if for the detection of trip hazards a minimum illuminance of 1.0 lux is sufficient (Fotios & Uttley 2018), it does not seem to be the case for pedestrian reassurance. Achieving balanced and optimal illuminance thresholds is a challenging task, but not only necessary but also of underlying impact in different sectors of society. The present work pinpoints several relevant aspects, methodological and technical, which can be considered in further research and policy.

Appendix A – Pictures of the test locations used in field study 1

Pictures taken in 2016 in daytime and after-dark during the experiment in the test locations R1 to R10.

Road 1

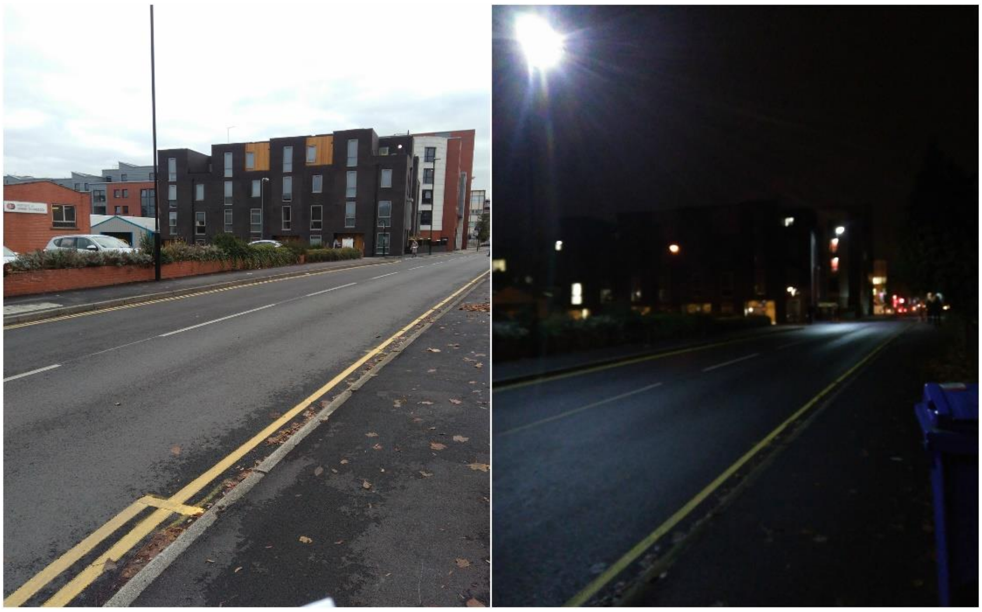
Road 2



Road 3

Road 4

Road 5

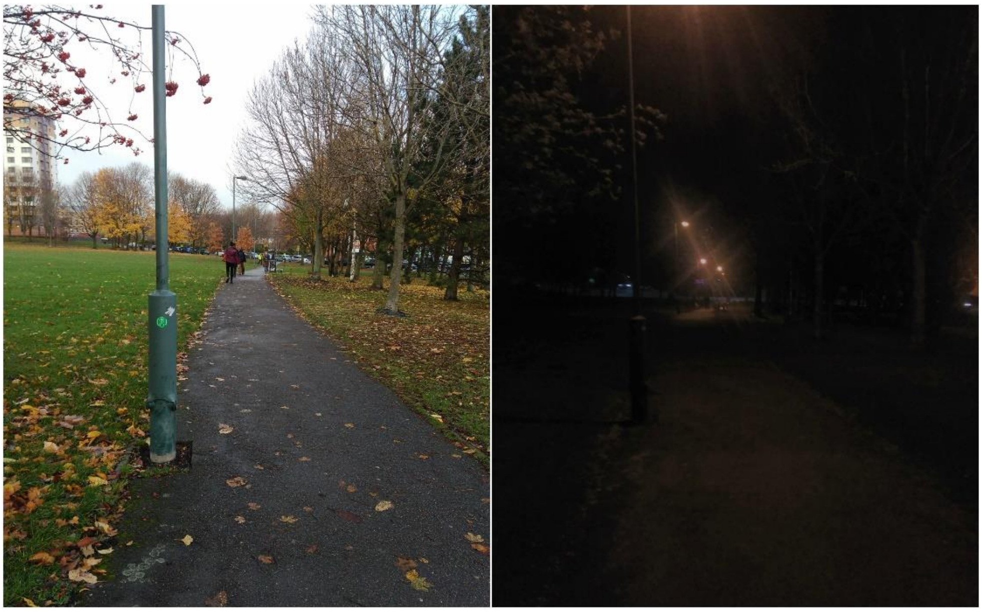


Road 6

Road 7

Road 8

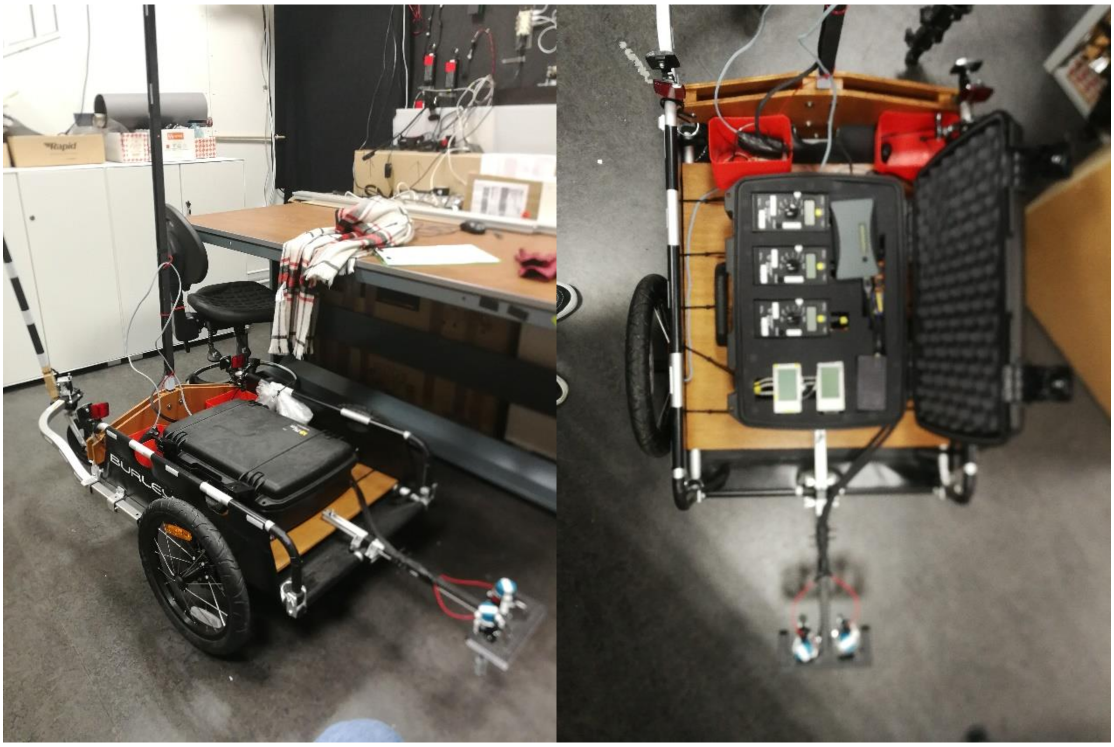
Road 9



Road 10

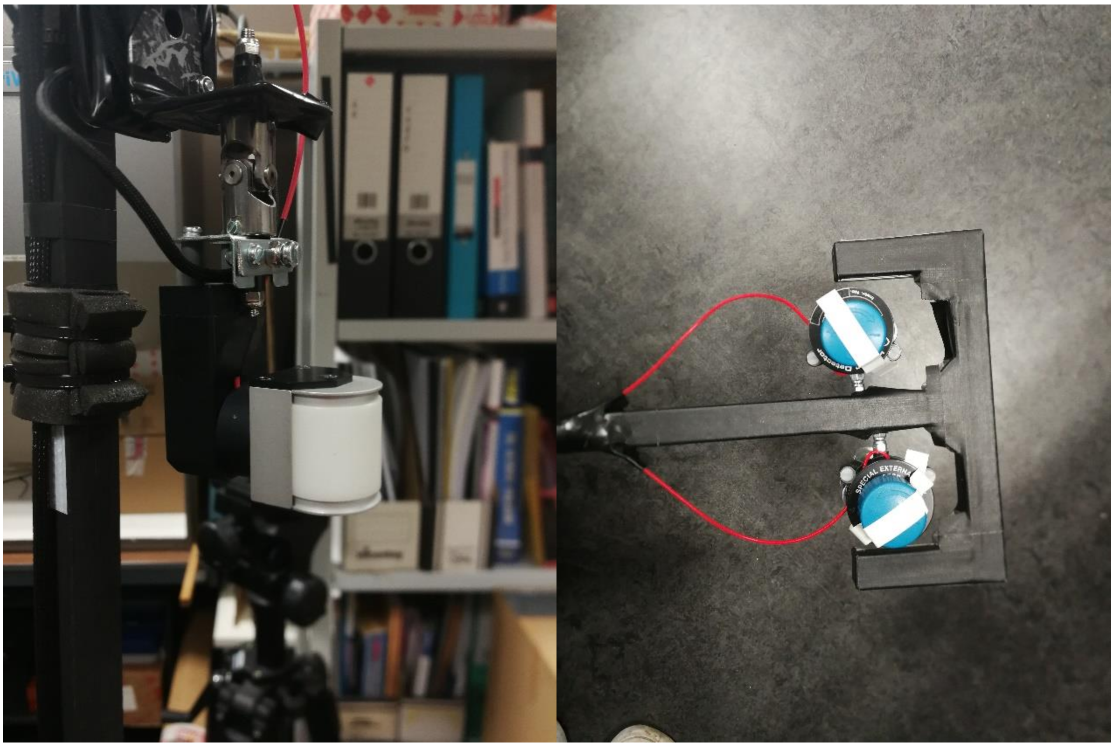
Appendix B – The lighting measurement apparatus

The trolley used to measure and record lighting data in the test locations used in field study 1 and 2.



The meters and loggers to register and save the data powered by a battery.

The sensors used to capture semi-cylindrical illuminance and horizontal and hemispherical illuminance, respectively.



Specifications of equipment

The specifications are described below as by the manufacturer.

1. HOBO 4-channel analogue logger - UX120-006M

Measurement Range:

4-20mA (w/CABLE-4-20MA) 0 to 20.1 mA

0 to 2.5 V (w/CABLE-2.5-STEREO)

0 to 5 V (w/CABLE-ADAP5)

0 to 10 V (w/ CABLE-ADAP10)

0 to 24 V (w/ CABLE-ADAP24)

UX120-006M Accuracy:

4-20mA ±0.001 mA ±0.2% of reading (w/CABLE-4-20MA)

±0.1 mV ±0.1% of reading (w/CABLE-2.5-STEREO)

±0.2 mV ±0.3% of reading (w/CABLE-ADAP5)

±0.4 mV ±0.3% of reading (w/ CABLE-ADAP10)

±1.0 mV ±0.3% of reading(w/ CABLE-ADAP24)

Resolution:

0.3 µA 4-20mA (w/CABLE-4-20MA)

40 µV (w/CABLE-2.5-STEREO)

80 µV (w/CABLE-ADAP5)

160 µV (w/ CABLE-ADAP10)

384 µV (w/ CABLE-ADAP24)

Logger

Operating range logging: -20° to 70°C (-4° to 158°F); 0 to 95% RH (non-condensing);

Launch/readout: 0° to 50°C (32° to 122°F) per USB specification

Logging rate: 1 second to 18 hours, 12 minutes, 15 seconds

Logging modes: Normal, burst, or statistics

Memory modes: Wrap when full or stop when full

Start modes: Immediate, push button, date & time, or next interval

Stop modes: When memory full, push button, or date & time

Restart mode: Push button

Time accuracy: ±1 minute per month at 25°C (77°F), see Plot A

Battery life: 1 year, typical with logging rate of 1 minute and sampling interval of 15 seconds or greater

Battery type: Two AAA 1.5 V alkaline batteries, user replaceable

Memory: 4 MB (1.9 million measurements, maximum)

Download type: USB 2.0 interface

Full memory download time: approximately 1.5 minutes

LCD: LCD is visible from 0° to 50°C (32° to 122°F); the LCD may react slowly or go blank in temperatures outside this range

Size: 10.8 x 5.41 x 2.54 cm (4.25 x 2.13 x 1 in.)

Weight: 107.5 g (3.79 oz)

Environmental rating: IP50

2. Hagner E4-X digital luxmeter

Detector: Vλ-filtered and cosine corrected sillicon photo diode

Measuring range: 0.01-199,900 lux

Accuracy: Better then ±3% (±1 in the last digit on the display)

Display: 3½ digits

Temperature range: -5° - +55°C

Output: 0 - 2V in steps of 1mV per displayed unit. Load impedance min 1,000 ohm

Power: 1 pc 9V type PP3 or battery eliminator

Weight: 0.42 kg (0,91 with carrying case)

Measurements: 150 x 85 x 50 mm

3. Detector SD10

Spectral response: Vλ-filtered

Order of absolute sensivity: 315 pA/hs.lux

4. Detector SD11

Spectral response: Vλ-filtered

Order of absolute sensivity: 100 pA/hcyl.lux

5. JETi Spectraval 1511

Optical parameters:

Spectral range - 380 … 780 nm (350 … 1000 nm NIR version)

Optical bandwidth - 4.5 nm (2 nm HiRes version)

Measuring range - Luminance 0.2 … 140 000 cd/m²

Measuring quantities:

Luminance, Radiance

xy and u' v' coordinates

Dominant wavelength, Color purity

Correlated Color Temperature (CCT)

CRI, CQS, TM-30

Circadian metrics, PAR

6. Powertraveller Gorilla

Features:

Up to 4-6 hours autonomy

Charge via AC

Adaptors supplied

Multi-voltage functionality and simultaneous charging via 5v USB

DC port

MPPT Solar Technology

Specifications:

Battery HD Lithium Polymer Rechargeable

Capacity: 9000mAh

Input voltage 9-25v

Output voltage: 8.4v/9.5v/10.5v/12v/16v/19v; and USB 5v

Dimensions 150 x 83 x 14 mm

Unit weight 265g

Appendix C – Questionnaire sample used in field study 1 and 2

Questionnaire used in daytime surveys, question marked with (*) was only introduced in field study 2.

I can see clearly around me	Strongly disagree	1	2	3	4	5	6	Strongly agree
How risky do you think it would be to walk alone here?*	Not at all risky	1	2	3	4	5	6	Very risky
Apart from the researcher and any other participants, there are lots of other people on the street	Strongly disagree	1	2	3	4	5	6	Strongly agree
How safe do you think this street is?	Very dangerous	1	2	3	4	5	6	Very safe
This street is kept in good condition	Strongly disagree	1	2	3	4	5	6	Strongly agree
I was born after 1879	Strongly disagree	1	2	3	4	5	6	Strongly agree
How anxious do you feel when walking down this street?	Very anxious	1	2	3	4	5	6	Not at all anxious
I can see a lot of litter and rubbish on this street	Strongly disagree	1	2	3	4	5	6	Strongly agree
I would rather avoid this street if I could	Strongly disagree	1	2	3	4	5	6	Strongly agree
How risky do you think it would be to walk alone here at night?	Not at all risky	1	2	3	4	5	6	Very risky
How familiar are you with this particular street?	Not at all familiar	1	2	3	4	5	6	Very familiar

Additional questions used in after-dark surveys.

The lighting on this street is:	Bad	1	2	3	4	5	6	Good
	Bright	1	2	3	4	5	6	Dark
	Not glaring	1	2	3	4	5	6	Glaring
	Unevenly spread (patchy)	1	2	3	4	5	6	Evenly spread (uniform)
Overall, how satisfied are you with the lighting on this street?	Very dissatisfied	1	2	3	4	5	6	Very satisfied

Appendix D – Field 1 recorded lighting data points in each location

The 20 data points registered per location for horizontal, hemispherical and semi-cylindrical illuminances.

Horizontal illuminance										
Road ID	1	2	3	4	5	6	7	8	9	10
1	27.6	21.6	14.1	7.1	3.1	1.7	3.5	7.7	16.3	26.0
1	3.1	3.3	2.3	1.6	1.4	1.3	1.5	1.7	2.4	3.2
2	1.5	1.8	1.6	1.2	1.0	0.8	0.5	0.8	1.6	2.3
2	17.6	15.2	5.3	3.0	1.1	1.0	1.6	1.4	6.8	16.9
3	5.0	4.1	3.8	3.2	3.7	4.9	7.4	12.3	21.2	27.2
3	18.2	19.5	21.0	19.3	11.5	7.2	6.0	5.0	5.6	6.7
4	18.9	18.2	8.0	3.1	6.0	8.4	9.6	13.7	15.4	26.3
4	7.1	6.8	5.2	7.4	4.8	3.4	3.1	4.3	5.8	6.3
5	17.7	19.4	12.7	8.9	7.1	4.7	4.2	5.8	10.7	17.9
5	7.7	6.8	5.6	4.3	3.5	4.3	5.0	6.3	8.0	9.6
6	12.3	11.7	11.6	9.7	7.9	5.7	6.0	6.8	8.2	8.8
6	5.0	5.8	4.0	5.7	5.5	5.5	5.5	5.7	6.1	6.9
7	4.3	4.3	3.7	3.2	3.8	3.9	3.6	6.3	7.8	19.0
7	2.2	1.9	1.8	2.2	3.1	4.6	4.9	9.2	18.7	30.3
8	4.2	3.6	2.8	2.0	1.2	1.2	1.2	1.4	1.9	2.6
8	15.5	15.7	7.7	1.7	1.3	1.3	2.1	4.3	10.5	17.4
9	27.5	17.3	8.5	4.2	1.8	1.1	1.1	2.4	4.6	8.0
10	32.5	62.8	77.5	78.9	67.4	35.7	28.5	55.9	68.1	75.0
Hemispherical illuminance										
Road ID	1	2	3	4	5	6	7	8	9	10
1	14.6	12.6	10.3	6.2	3.1	2.1	3.9	6.3	8.4	14.0
1	2.5	2.6	2.0	1.6	1.5	1.4	1.5	1.7	2.1	2.6
2	1.6	1.8	2.0	1.4	1.2	0.9	1.2	1.4	1.8	2.3
2	9.1	9.7	4.4	2.9	1.5	1.4	1.3	2.2	2.6	8.8
3	4.8	4.2	4.1	3.7	4.1	6.0	6.7	11.5	16.0	17.1
3	14.9	15.1	16.5	16.2	11.3	7.3	6.3	5.2	5.6	5.9
4	10.7	11.2	5.9	3.3	4.1	6.7	7.7	9.5	11.3	15.6
4	5.7	5.6	4.8	5.4	4.9	3.5	3.6	4.3	5.4	6.2
5	11.4	12.1	8.7	7.2	6.2	4.0	2.7	4.3	6.5	9.5
5	5.5	5.2	4.7	5.8	4.2	5.0	5.5	5.9	6.7	8.0
6	6.8	7.1	7.4	6.5	6.5	4.8	4.7	4.9	5.2	5.4
6	4.1	4.8	4.8	4.8	4.8	5.0	4.9	5.1	5.3	5.6
7	4.5	4.2	3.9	3.5	3.8	3.5	5.1	5.6	5.1	10.9
7	2.5	2.1	2.5	2.1	3.2	3.0	5.1	4.2	8.9	17.0
8	3.9	3.6	3.0	2.4	1.6	1.5	1.7	1.7	2.0	2.4
8	8.7	10.8	5.8	1.8	1.5	1.4	1.6	2.9	4.3	9.5
9	14.3	10.5	6.1	3.9	2.0	1.3	1.7	2.3	2.5	4.8
10	31.5	59.3	77.6	77.9	67.2	40.6	33.3	55.7	68.2	74.1
Semi-cylindrical illuminance										

Road ID	1	2	3	4	5	6	7	8	9	10
1	8.8	16.4	12.5	6.5	2.3	1.2	1.6	4.5	6.6	10.0
1	1.5	2.2	1.8	1.5	1.0	0.8	0.7	1.7	1.4	1.5
2	1.5	2.0	2.2	2.0	1.7	1.5	1.2	1.2	1.4	1.4
2	8.2	9.6	7.8	4.4	1.1	0.8	0.8	0.8	1.1	1.4
3	4.4	4.9	4.6	4.8	5.9	4.9	5.6	5.8	6.0	5.9
3	12.8	14.3	17.0	16.7	10.1	7.4	5.9	5.6	4.0	3.8
4	11.0	14.7	8.9	4.4	3.7	3.8	3.8	3.8	3.7	8.3
4	6.3	6.4	6.1	8.9	7.7	6.1	5.0	5.3	5.8	6.4
5	4.8	10.3	7.7	7.2	5.8	2.8	1.3	0.8	0.7	0.7
5	4.2	5.2	5.3	5.4	4.6	4.1	2.7	2.5	4.0	4.0
6	2.9	4.7	6.6	4.9	5.2	3.9	2.8	2.1	1.8	1.5
6	4.1	4.0	4.4	4.8	4.5	4.6	4.9	4.4	4.8	5.5
7	4.0	5.0	5.2	4.8	3.8	3.8	3.3	2.9	2.3	1.9
7	1.8	1.8	1.8	1.8	1.9	1.9	1.8	2.0	2.4	2.7
8	1.4	1.6	1.6	1.4	1.2	1.1	1.0	0.9	0.8	1.0
8	2.8	7.8	4.5	1.8	0.9	1.2	1.6	2.6	5.0	2.4
9	11.0	10.3	8.4	3.2	1.8	1.1	1.0	0.7	1.1	2.0
10	25.8	53.8	71.2	74.4	71.3	39.2	26.8	52.4	64.3	72.8

Appendix E – Field study 2 preliminary lighting measurements data points and estimations

These measurements were taken in six points of a chosen segment in each location from a pool of 23 streets. These were used to estimate illuminances according to Yao et al (2018) and choose locations for field study 2.

Road	**Distance between lamps (in meters)**	**Lamp side – Horizontal illuminance**			**Other side – Horizontal illuminance**			**Horizontal Illuminance Estimation**		
		Below lamp	**¼ distance**	**½ distance**	**Parallel below lamp**	**¼ distance**	**½ distance**	**Mean**	**Min**	**U_o Min/Av**
1	24	14.69	10.6	4.69	5.4	3.8	3.6	7.13	3.6	0.505
2	29.4	11.76	10.6	6	5.35	6.1	6.5	7.71	5.35	0.693
3	33.3	2.11	1.09	0.38	1.2	0.74	0.37	0.98	0.37	0.377
4	34.6	23.4	14.74	4.18	10.75	9.8	3.8	11.11	3.8	0.342
5	29.8	13.31	4.55	1.91	4.08	3.35	2.51	4.95	1.91	0.386
6	26.2	23.54	9.59	2.68	11.77	7.95	3.2	9.79	2.68	0.274
7	41.6	16.64	7.65	2.07	8.13	5.17	3.3	7.16	2.07	0.289
8	42.1	19.47	5.05	1.37	4.82	4.13	2.15	6.17	1.37	0.222
9	23.3	10.54	7.67	4.96	4.74	5.09	4.27	6.21	4.27	0.687
10	25.7	18.84	12.29	3.75	7.58	4.56	4.56	8.60	3.75	0.436
11	31.9	23.28	9.75	2.81	7.31	6.56	1.27	8.49	1.27	0.149
12	37.1	20.74	7.3	2.01	7.28	3.7	2.34	7.23	2.01	0.278
13	30.7	14.17	8.48	4.48	4.84	4.02	3.39	6.56	3.39	0.517
14	25.1	26.39	0.45	0.9	11.87	7.74	2.3	8.28	0.45	0.054
15	30.5	25.98	20.72	5.18	4.93	3.33	2.59	10.46	2.59	0.248
16	41.1	2.5	2.8	3.8	1.4	2.15	3.48	2.69	1.4	0.521
17	27.3	21.16	18.89	5.65	2.74	2.24	2.18	8.81	2.18	0.247
18	22.4	22.6	13.24	5.25	2.7	1.75	2.57	8.02	1.75	0.218
19	33.6	32.4	9.42	1.56	8.27	3.38	2.35	9.56	1.56	0.163
20	30.7	16.83	11.14	4.01	3.2	2.77	2.21	6.69	2.21	0.330
21	46	21.3	8.2	2.59	9.09	3.07	2.8	7.84	2.59	0.330
22	26.9	18.53	6	1.51	7.26	2.8	4.3	6.73	1.51	0.224
23	35.7	20.1	14.4	3.82	5.21	3.78	2.8	8.35	2.8	0.335

Appendix F – Field 2 recorded lighting data points in each location

The 20 data points registered per location for horizontal, hemispherical and semi-cylindrical illuminances.

Horizontal illuminance																	
Road ID	***1***	***2***	***3***	***4***	***5***	***6***	***7***	***8***	***9***	***10***	***11***	***12***	***13***	***14***	***15***	***16***	***17***
1	16.79	8.08	2.98	2.96	1.49	1.06	0.65	0.53	0.97	1.60	0.15	2.06	2.34	1.06	2.73		
1	19.24	10.44	4.42	2.29	1.39	3.80	2.76	1.39	1.83	2.37	3.04	3.85	4.61	5.04	5.09		
2	5.85	5.72	5.75	5.46	5.72	5.94	7.69	10.42	10.63	8.93							
2	17.12	11.93	7.89	5.10	4.09	7.05	10.21	14.58	18.17	17.61							
3	32.03	22.00	13.71	9.59	7.43	7.44	8.05	9.96	11.78	13.57	15.12	9.68	15.33	14.66	11.90		
3	6.80	3.41	5.24	6.57	6.04	5.51	5.26	5.59	5.76	6.00	6.75	7.45	9.02	9.18	9.80		
4	23.79	18.63	11.93	8.26	6.29	3.75	1.59	1.02	1.12	3.96	7.62	12.16	16.67	22.14	24.99		
4	6.61	5.77	4.88	3.61	2.68	1.98	1.50	3.38	3.88	5.22	6.87	9.76	30.02	34.28	48.27		
5	6.25	4.46	3.75	2.12	3.83	4.33	4.31	4.54	1.10	4.89							
5	9.79	8.16	3.72	1.80	2.48	3.13	5.78	7.92	5.77	7.49							
6	6.75	3.75	2.21	1.74	1.63	1.98	4.47	7.40	8.80	2.91							
6	2.79	3.48	3.05	2.12	1.44	1.23	1.28	1.66	1.54	2.12							
7	1.60	1.46	1.16	0.98	0.87	0.94	0.71	0.64	0.57	0.51	0.97	0.74	0.97	1.21	1.40	2.10	1.72
7	2.42	1.83	1.21	0.83	0.67	0.50	0.39	0.36	0.49	0.43	0.50	0.79	1.18	1.70	2.34	2.62	2.61
8	20.80	19.86	15.55	9.78	2.90	2.20	4.01	4.66	5.43	5.71							
8	13.95	8.76	7.78	5.80	3.11	2.71	5.44	5.88	5.99	5.84							
9	15.67	10.31	5.94	6.60	6.53	8.05	11.55	15.13	16.10	15.95							
9	7.13	7.15	6.48	5.78	5.78	5.82	5.67	5.80	5.68	5.83							
10	15.85	10.36	5.95	3.10	2.23	2.14	5.68	10.31	18.33	21.58							
10	5.25	3.98	3.22	3.36	3.59	4.17	5.55	7.28	8.48	8.21							
11	1.10	1.07	1.84	2.91	3.72	6.07	9.76	17.28	27.62	28.88							
11	7.41	5.54	4.19	2.92	1.97	1.56	1.17	1.06	0.94	0.86							
12	4.76	3.90	2.88	2.13	3.66	4.92	5.57	6.18	6.40	6.34							

12	22.63	17.58	8.97	4.40	2.60	2.36	5.50	8.67	13.60	15.19							
13	15.83	10.64	5.36	2.93	2.34	0.85	1.42	1.71	2.29	4.99	8.23	13.97	21.36	26.07	25.79		
13	11.28	9.54	8.15	6.11	4.36	5.34	6.14	5.04	3.48	3.64	5.04	7.03	11.40	13.29	14.41		
14	20.42	19.09	6.06	9.36	0.60	9.09	2.44	2.04	2.63	3.04	5.76	9.54	17.07	19.98	19.83		
14	7.98	6.62	4.58	3.27	2.83	2.87	1.90	1.90	2.34	3.19	4.46	6.22	7.74	8.54	8.47		
15	20.97	13.62	6.55	3.74	1.99	1.32	0.84	0.40	1.36	2.09	2.89	3.37	3.47	3.34	3.51		
15	20.45	12.23	6.26	3.12	2.01	1.09	0.98	1.32	1.62	2.09	2.94	3.24	3.44	4.37	4.46		
16	16.85	11.15	7.37	4.73	4.29	5.55	7.43	10.61	11.81	11.62							
16	5.48	4.83	4.09	3.77	4.14	4.84	6.34	7.58	8.22	8.46							

Hemispherical illuminance

Road ID	***1***	***2***	***3***	***4***	***5***	***6***	***7***	***8***	***9***	***10***	***11***	***12***	***13***	***14***	***15***	***16***	***17***
1	9.62	4.96	3.36	0.80	0.95	0.72	0.81	0.87	1.28	1.87	0.33	2.27	1.85	2.14	2.10		
1	11.57	7.56	4.36	2.60	2.02	3.34	3.30	1.56	2.30	2.53	3.08	3.59	3.89	4.41	4.47		
2	4.01	4.17	3.61	4.65	5.02	5.11	6.47	8.83	7.95	6.59							
2	9.47	7.24	6.04	4.30	5.28	5.49	6.80	8.58	9.38	9.23							
3	16.70	14.22	10.12	7.62	6.14	7.05	6.82	7.45	8.69	9.91	10.74	8.66	10.42	10.69	8.79		
3	5.12	3.16	4.33	4.18	4.26	4.17	4.31	4.92	5.07	5.25	5.68	6.10	6.79	7.02	7.17		
4	14.59	13.96	8.85	6.60	5.32	3.60	1.78	1.30	2.78	3.35	4.91	6.99	8.94	11.21	12.54		
4	4.84	4.56	4.13	3.42	3.00	2.94	3.14	3.50	3.80	4.46	6.04	7.38	18.04	20.61	41.66		
5	26.21	16.29	12.94	9.59	3.63	3.82	3.46	3.35	1.21	3.47							
5	6.40	5.04	3.02	1.57	2.42	2.64	3.82	5.27	3.94	4.98							
6	2.59	2.36	2.15	2.22	5.22	2.76	4.94	6.72	8.52	9.94							
6	5.18	4.34	3.21	2.53	2.55	1.74	3.60	2.39	10.10	10.76							
7	1.15	1.15	0.95	0.87	0.86	1.03	0.76	0.71	0.62	0.63	1.20	0.80	0.96	1.58	1.33	5.00	1.35
7	1.70	1.43	1.08	0.87	0.78	0.72	0.52	0.54	0.55	0.61	0.68	0.77	0.99	1.28	1.55	1.68	1.66
8	17.09	21.02	20.03	12.91	4.62	2.53	3.18	3.27	3.85	4.10							
8	8.18	6.36	6.69	5.15	5.14	3.98	5.71	6.19	5.47	5.05							
9	9.34	7.11	6.12	3.88	5.17	2.60	7.03	8.46	8.94	8.82							
9	5.42	5.22	4.94	4.69	4.76	4.82	4.69	4.43	4.36	4.35							
10	8.79	7.14	4.98	2.84	2.35	3.91	4.10	6.27	9.59	11.05							

10	3.84	3.25	3.01	3.10	3.25	3.62	4.23	5.10	5.64	5.28							
11	0.80	0.86	1.65	2.57	3.16	4.29	6.22	10.17	14.55	14.95							
11	6.00	5.07	4.29	3.15	2.33	1.86	1.39	1.17	1.05	0.97							
12	4.01	3.31	2.92	2.33	4.10	4.92	5.34	5.47	5.72	5.45							
12	12.18	10.72	6.45	4.32	2.34	2.48	3.79	5.23	7.26	7.90							
13	9.06	6.99	3.86	2.15	2.07	1.93	1.73	2.21	2.72	4.44	6.39	9.24	11.92	13.76	13.43		
13	7.88	7.30	6.82	5.58	4.62	4.24	4.99	4.35	3.57	3.45	5.15	6.19	9.15	9.62	10.08		
14	10.52	4.84	4.97	5.19	0.62	4.34	2.13	2.50	2.88	3.06	4.72	6.79	10.05	11.17	11.10		
14	5.16	4.61	3.59	2.96	2.62	3.03	2.07	1.94	2.17	2.53	3.23	4.03	4.75	5.14	5.24		
15	12.26	8.91	5.67	3.80	2.44	1.81	1.19	0.78	1.56	2.06	2.59	2.98	2.84	2.79	3.20		
15	11.38	8.06	5.09	3.11	2.17	1.58	1.25	1.62	1.38	2.10	4.41	3.30	3.55	3.79	3.89		
16	9.81	7.86	5.77	4.28	4.08	3.01	4.87	5.96	6.35	6.19							
16	4.30	4.12	3.70	3.49	3.74	4.09	5.36	6.02	5.96	6.15							
Semi-cylindrical illuminance																	
Road ID	***1***	***2***	***3***	***4***	***5***	***6***	***7***	***8***	***9***	***10***	***11***	***12***	***13***	***14***	***15***	***16***	***17***
1	1.23	1.35	1.07	1.06	1.33	1.40	1.44	1.80	1.99	2.46	2.87	4.38	2.22	2.83	3.92		
1	12.76	8.48	6.62	3.13	2.13	2.30	1.53	1.20	1.15	1.23	1.41	1.95	2.33	2.73	3.06		
2	4.52	5.21	6.10	4.92	4.81	3.88	4.18	5.03	5.39	5.41							
2	7.07	8.78	6.69	5.08	3.78	2.72	1.67	1.17	1.31	4.14							
3	15.63	12.99	8.89	7.08	4.86	3.89	3.64	3.49	3.39	4.44	3.99	5.07	5.54	5.05	5.45		
3	4.67	4.90	6.33	6.61	5.56	5.35	4.91	4.77	4.27	4.70	5.18	5.42	7.68	7.42	5.91		
4	12.87	7.80	5.66	6.33	5.28	3.21	1.90	1.15	0.89	0.64	0.74	0.96	0.72	0.79	3.40		
4	3.41	3.65	3.96	3.48	3.06	2.58	2.46	1.80	1.32	1.27	1.75	2.68	13.30	16.17	15.34		
5	9.25	6.19	5.33	3.99	3.72	2.74	3.05	3.02	2.84	2.87							
5	2.56	2.72	1.38	1.40	2.01	2.24	3.52	3.22	2.18	1.53							
6	6.75	3.75	2.21	1.74	1.63	1.98	4.47	7.40	8.80	2.91							
6	2.79	3.48	3.05	2.12	1.44	1.23	1.28	1.66	1.54	2.12							
7	0.78	0.85	0.67	0.49	0.44	0.58	0.38	0.37	0.47	0.46	0.63	0.75	0.94	1.23	1.50	11.12	1.35
7	1.38	1.37	1.07	0.83	0.72	0.71	0.43	0.31	0.28	0.31	0.26	0.28	0.30	0.28	0.40	0.46	0.49
8	9.02	11.30	12.27	9.15	3.95	3.18	2.83	2.78	3.69	4.41							

8	8.44	6.74	4.78	5.67	6.97	6.31	5.79	6.81	6.01	5.68							
9	8.80	8.41	6.53	4.24	3.19	3.09	2.43	2.31	2.84	3.06							
9	5.27	5.43	6.18	5.37	4.98	4.47	2.93	2.30	2.09	2.09							
10	8.08	7.18	5.08	3.22	1.82	0.96	0.91	0.65	0.71	3.38							
10	3.90	3.86	2.76	2.12	1.73	2.28	2.83	3.80	4.46	4.96							
11	0.96	1.23	1.08	1.87	1.23	1.23	2.16	1.86	3.14	6.11							
11	5.51	5.54	4.95	2.95	1.76	1.14	0.90	0.82	0.80	0.75							
12	2.26	3.49	3.35	2.68	2.58	2.26	2.31	2.42	1.50	3.15							
12	12.59	11.96	8.46	2.06	0.82	0.58	0.83	0.86	1.25	1.98							
13	1.38	0.83	0.73	0.65	0.60	0.57	0.63	0.95	1.74	4.86	7.05	10.71	13.91	10.92	3.19		
13	4.95	6.22	6.46	4.88	2.68	1.60	2.02	2.39	1.50	1.51	1.76	2.36	3.29	3.53	2.83		
14	2.27	3.35	1.01	3.30	0.81	0.66	0.97	1.59	3.07	3.75	5.37	8.17	9.93	8.54	2.53		
14	5.82	5.85	5.17	3.80	3.13	2.08	0.94	0.65	0.66	0.83	1.31	2.18	2.33	4.06	3.94		
15	10.12	9.16	6.86	4.13	3.07	1.76	0.97	0.62	0.48	0.46	0.66	0.76	0.73	0.89	1.48		
15	12.25	8.64	6.31	4.47	1.57	0.68	0.44	0.58	0.64	0.58	1.46	1.17	0.99	1.38	1.66		
16	6.20	8.98	6.42	5.05	3.84	2.53	1.42	1.07	0.85	2.71							
16	3.92	3.84	2.98	1.94	1.40	1.44	2.60	2.77	4.55	4.92							

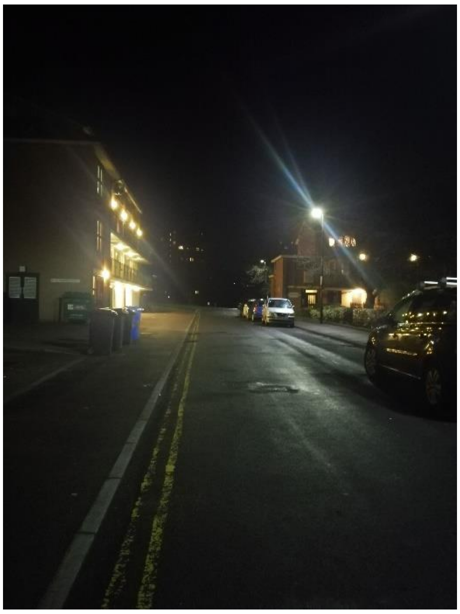
Appendix G – Pictures of the test locations used in field study 2

Pictures taken in 2019 after-dark during the lighting measurements in the test locations R1 to R16 of field study 2.

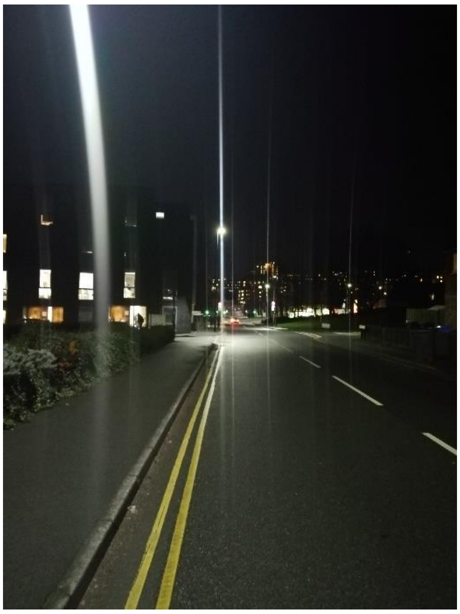
Road 1

Road 3

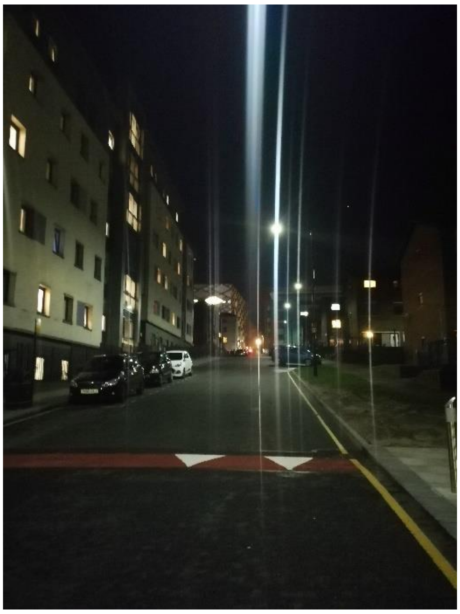
Road 2



Road 4



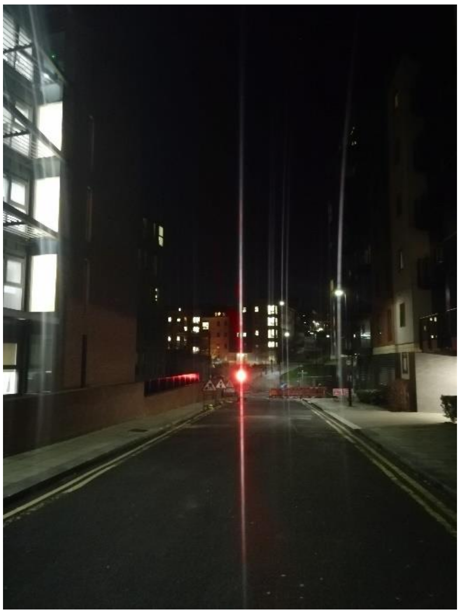
Road 5



Road 6

Road 7

Road 8



Road 9

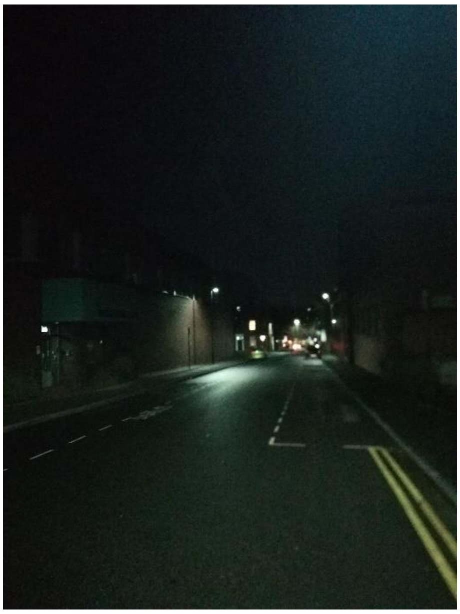
Road 10

Road 11

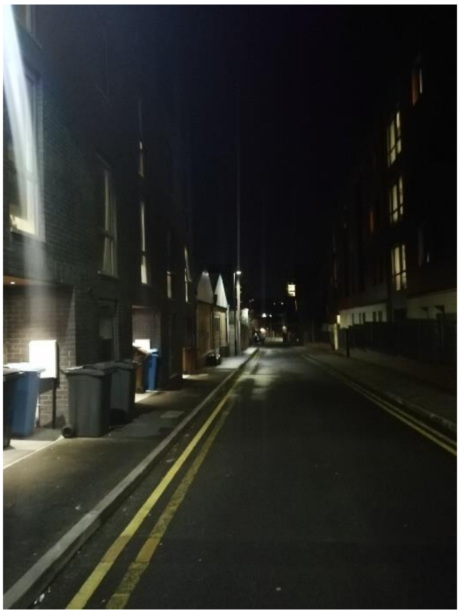
Road 12

Road 13

Road 15



Road 14



Road 16

Appendix H – Mean ratings for daytime and after-dark for N=16

Field study 2 mean ratings for daytime and after dark for N=16 for the variables X.

Daytime									
Road	**See_clearly**	**Walk_Alone**	**People**	**Safe**	**Good_condition**	**Anxious_walking**	**Litter**	**Avoid_street**	**Familiar_street**
1	5.80	4.47	2.51	4.63	4.19	3.73	2.32	3.67	3.18
2	5.71	4.26	2.88	4.31	3.98	3.43	2.72	3.53	3.18
3	5.69	3.76	3.71	4.17	3.74	3.11	3.32	3.15	4.25
4	5.86	3.57	3.79	4.25	3.95	3.43	3.67	3.33	3.65
5	5.66	2.98	4.38	4.76	4.49	3.95	4.23	3.21	4.28
6	5.74	2.49	4.59	4.93	4.94	4.58	4.64	3.81	3.15
7	5.83	4.97	2.94	4.71	5.14	5.03	4.86	4.54	3.23
8	5.74	4.69	2.51	4.74	5.17	5.23	4.86	4.83	3.57
9	5.91	5.51	4.23	5.43	4.91	5.54	4.57	5.43	5.11
10	5.74	4.37	2.29	4.37	4.57	4.80	4.54	4.37	2.51
11	5.66	4.37	1.80	4.37	4.51	4.71	4.37	4.40	2.17
12	5.77	4.49	1.86	4.54	5.17	4.74	5.09	4.20	1.94
13	5.66	4.06	1.80	3.97	3.86	4.54	4.06	3.91	1.77
14	5.57	3.89	1.63	4.09	4.66	4.34	4.37	3.77	2.11
15	5.49	4.17	2.00	4.23	4.54	4.66	4.69	4.14	2.31
16	5.74	4.29	1.29	4.23	4.00	4.63	4.00	3.71	1.60
After-dark									
Road	**See_clearly**	**Walk_Alone**	**People**	**Safe**	**Good_condition**	**Anxious_walking**	**Litter**	**Avoid_street**	**Familiar_street**
1	3.34	2.90	2.29	4.58	3.45	3.35	2.21	2.51	2.03
2	4.60	2.67	3.19	4.12	3.74	3.41	2.64	2.73	1.69
3	4.80	2.77	3.66	4.13	3.85	3.28	3.28	2.83	3.37
4	4.49	2.42	3.91	4.19	4.12	3.62	3.66	3.11	2.37
5	5.06	2.74	4.26	4.75	4.68	4.24	4.36	3.51	4.14

6	4.43	2.80	4.40	4.98	5.11	4.80	5.01	4.00	1.83
7	2.69	3.34	2.89	3.63	4.66	3.71	5.06	3.31	3.03
8	4.83	4.71	2.97	4.80	4.97	5.17	5.11	4.94	3.57
9	4.80	5.37	4.60	5.31	5.00	5.49	4.83	5.11	4.97
10	4.20	3.91	2.29	3.94	4.20	4.11	4.71	3.74	2.20
11	4.77	4.03	1.80	3.97	4.29	4.37	4.60	3.69	1.97
12	4.66	3.97	1.37	3.77	4.63	4.17	5.17	3.83	1.71
13	4.34	3.89	1.74	3.74	4.06	4.23	4.49	3.26	1.60
14	4.34	3.51	1.40	3.43	4.43	3.71	4.89	3.20	2.23
15	3.60	3.29	1.89	3.51	4.23	3.69	4.77	3.37	2.06
16	4.40	3.83	1.37	3.71	4.20	3.86	4.71	3.66	1.66

Appendix I – Papers published resulting from this work

Copyright note

Some of the material in the published papers listed below has been reproduced within this thesis. The copyright policy of the journal in which the papers are published allows authors to retain copyright in the work. Permission for reproduction within this thesis has also been granted by co-authors.

Journal

Fotios, S., Monteiro, A. L., and Uttley, J. (2019). Evaluation of pedestrian reassurance gained by higher illuminances in residential streets using the day–dark approach. *Lighting Research & Technology*, **51**(4), 557-575.

Conference(s)

Fotios, S., Monteiro, A. L. (2019). Uniformity predicts pedestrian reassurance better than average illuminance (Poster PO180). *CIE Quadrennial meeting*, Washington DC, USA. DOI 10.25039/x46.2019.PO180

Monteiro, A. L. (2018). Road lighting and reassurance: a cognitive, emotional and behavioural approach. *Lumenet: A Research Methods Workshop for PhD Students of Lighting, Colour, Daylight and Related Subjects.* Copenhagen, Denmark.

Monteiro, A. L., Fotios, S., Uttley, J. Pedestrian reassurance and road lighting: minimum illuminance is a better predictor than mean illuminance. *Light Source: the 16th international symposium on the science and the technology of lighting.* Sheffield, United Kingdom.

Fotios, S., Monteiro A. L., Uttley, J., Mattoni, B., Bisegna, F. (2018). Does higher illuminance encourage reassurance that it is safe to walk? Comparing different methods of analysis. *Lux Europa2017: Lighting for Modern Society*. Ljubljana Slovenia, 25-30.

Monteiro, A. L., Uttley, J. & Fotios, S. (2017) 059. Road lighting and reassurance – cognitive, emotional and behavioural responses. *International Conference on Environmental Psychology 2017: Theories of change and social innovation in transitions towards sustainability.* A. Coruna, Spain.

Appendix J – Acknowledgement of collaborative work within the thesis

The candidate confirms that the work submitted is their own, except where work that has formed part of jointly authored publications has been included. The contribution of the candidate and the other authors to this work has been explicitly indicated below. The candidate confirms that appropriate credit has been given within the thesis where reference has been made to the work of others.

Fotios, S., Monteiro, A. L., and Uttley, J. (2019). Evaluation of pedestrian reassurance gained by higher illuminances in residential streets using the day–dark approach. *Lighting Research & Technology*, **51**(4), 557-575.

The abovementioned journal paper was authored by Prof. Steve Fotios, the candidate's supervisor, and co-authored by the candidate, Aleksandra Liachenko Monteiro, and a departmental senior colleague, Dr. Jim Uttley. Part of this analysis is reported in chapter 4, as field study 1.

I, the candidate was responsible for the field study, data collection and its entry for analysis, of which, I, the candidate was partially responsible. Dr. Jim Uttley was responsible for the regression modelling and consequent estimations in this publication. I, the candidate delivered pieces of written work regarding methodology and analysis to Prof. Steve Fotios, who with the co-author wrote the paper, under the guidance and commentary of the first.

References

Adams, R. E., and Serpe, R. T. (2000). Social integration, fear of crime, and life satisfaction. *Sociological perspectives*, 43(4), 605-629.

Aditjandra, P. T., Mulley, C., and Nelson, J. D. (2013). The influence of neighbourhood design on travel behaviour: Empirical evidence from North East England. *Transport Policy*, **26**, 54-65.

Ailin, C., Zaizhou, L. I., Qipeng, H. E., Xiaoyang, H. E., Zhisheng, W., and Nianyu, Z. (2018). Study on Matching Value of Illumination in Night Lighting Environments. In: *2018 15th China International Forum on Solid State Lighting: International Forum on Wide Bandgap Semiconductors Chin,* China: SSLChina: IFWS, 1-4.

Akaike, H. (1974). A new look at the statistical model identification. *IEEE transactions on automatic control*, **19**(6), 716-723.

Alfaro-Beracoechea, L., Puente, A., Da Costa, S., Ruvalcaba, N., and Páez, D. (2018). Effects of fear of crime on subjective well-being: A meta-analytic review. *European Journal of Psychology Applied to Legal Context*, **10**(2), 89-96.

Andrews, M., and Gatersleben, B. (2010). Variations in perceptions of danger, fear and preference in a simulated natural environment. *Journal of Environmental Psychology*, **30**(4), 473-481.

Appleton, J. (1975). *The experience of landscape*. London: William Clowes.

Atkins, S., Husain, S., and Storey, A. (1991). The influence of street lighting on crime and fear of crime. *Crime Prevention Unit Papers*. [Viewed 13th February 2021] Available in: http://modresvetlo.cz/PDF/The_Influence_of_Street_Lighting_on_Crime_and_Fear_of_Crime.pdf

Bandura, A. (1997). *Self Efficacy: The Exercise of Control*. Worth.

Barkus, E., Yavorsky, C., and Foster, J. (2006). Understanding and Using Advanced Statistics. *Faculty of Health & Behavioural Sciences-Papers*, 393.

Barni, D., Vieno, A., Roccato, M., and Russo, S. (2016). Basic personal values, the country's crime rate and the fear of crime. *Social Indicators Research*, **129**(3), 1057-1074.

Bhagavathula, R., and Gibbons, R. B. (2020). Light levels for parking facilities based on empirical evaluation of visual performance and user perceptions. *Leukos*, **16**(2), 115-136.

Bishop, I. D., and Rohrmann, B. (2003). Subjective responses to simulated and real environments: a comparison. *Landscape and Urban Planning*, **65**(4), 261-277.

Blöbaum, A., and Hunecke, M. (2005). Perceived danger in urban public space: The impacts of physical features and personal factors. *Environment and Behavior*, **37**(4), 465-486.

Boateng, F. D. (2019). Fearfulness in the community: Empirical assessments of influential factors. *Journal of interpersonal violence*, **34**(3), 562-584.

Boessen, A., Hipp, J. R., Butts, C. T., Nagle, N. N., and Smith, E. J. (2017). Social fabric and fear of crime: Considering spatial location and time of day. *Social Networks*, **51**, 60-72.

Bolger, M. A., and Bolger, P. C. (2019). Predicting Fear of Crime: Results from a Community Survey of a Small City. *American Journal of Criminal Justice*, **44**(2), 334-351.

Boomsma, C., and Steg, L. (2014). Feeling safe in the dark: Examining the effect of entrapment, lighting levels, and gender on feelings of safety and lighting policy acceptability. *Environment and Behavior*, **46**(2), 193-212.

Boyce, P. R., Eklund, N. H., Hamilton, B. J., and Bruno, L. D. (2000). Perceptions of safety at night in different lighting conditions. *International Journal of Lighting Research and Technology*, **32**(2), 79-91.

Boyce, P. R. (2014). *Human factors in lighting*. Crc Press.

Box, S., Hale, C., and Andrews, G. (1988). Explaining fear of crime. *The British Journal of Criminology*, **28**(3), 340-356.

British Standards Institution. PD CEN/TR 13201-1:2014. *Road lighting. Part 1: Guidelines on Selection of Lighting Classes*. London: BSI, 2014.

British Standards Institution. BS EN 13201-2:2015. *Road lighting. Part 2: Performance requirements.* London: BSI, 2015.

British Standards Institution. BS EN 13201-3:2015. *Road lighting. Part 3: Calculation of performance*. London: BSI, 2015.

British Standards Institution. BS EN 12665:2018. *Light and lighting - Basic terms and criteria for specifying lighting requirements*. London: BSI, 2018.

British Standards Institution. BS EN 5489-1:2020. *Design of road lighting. Part 1: Lighting of roads and public amenity areas — Code of practice*. London: BSI, 2020.

Bullough J.D., Snyder J.D., and Kiefer K. (2019) Impacts of average illuminance, spectral distribution, and uniformity on brightness and safety perceptions under parking lot lighting. *Lighting Research and Technology*, DOI: 1477153519875171

Canter, D. (1977) *The Psychology of Place*. The architectural press Ltd.: London.

Castro-Toledo, F. J., Perea-García, J. O., Bautista-Ortuño, R., and Mitkidis, P. (2017). Influence of environmental variables on fear of crime: Comparing self-report data with physiological measures in an experimental design. *Journal of Experimental Criminology*, **13**(4), 537-545.

Chadee, D., Ali, S., Burke, A., and Young, J. (2017). Fear of crime and community concerns: Mediating effect of risk and pragmatic fear. *Journal of Community & Applied Social Psychology*, **27**(6), 450-462.

Chappell, A. T., Monk-Turner, E., and Payne, B. K. (2011). Broken windows or window breakers: The influence of physical and social disorder on quality of life. *Justice Quarterly*, **28**(3), 522-540.

Chattamvelli, R., and Shanmugam, R. (2015). *Statistics for scientists and engineers*. John Wiley & Sons, Incorporated.

Chatterjee, S., and Hadi, A. S. (2012). *Regression analysis by example*. John Wiley & Sons.

Chon, D. S., and Wilson, M. (2016). Perceived risk of burglary and fear of crime: Individual- and country-level mixed modeling. *International journal of offender therapy and comparative criminology*, **60**(3), 308-325.

Cohen, J. (1992). A power primer. *Psychological bulletin*, 112(1), 155.

Collins, R. E. (2016). Addressing the inconsistencies in fear of crime research: A meta-analytic review. *Journal of criminal justice*, **47**, 21-31.

Commission Internationale De L'Eclairage. (2010). *Lighting of Roads for Motor and Pedestrian Traffic: CIE 115: 2010*. CIE.

Commission Internationale De L'Eclairage. (2014). *Lighting of Roads for Motor and Pedestrian Traffic: CIE 206: 2014*. CIE.

Curtis, B. and Curtis, C. (2011). Social Research: A Practical Introduction. 55 City Road, London: SAGE Publications.

Davidson, N., and Goodey, J. (1991). *Street Lighting and Crime: The Hull Project*. Hull University, Hull.

Deb, S., Strawderman, L. J., and Carruth, D. W. (2018). Investigating pedestrian suggestions for external features on fully autonomous vehicles: A virtual reality experiment. *Transportation research part F: traffic psychology and behaviour*, **59**, 135-149.

De Donder, L., Buffel, T., Dury, S., De Witte, N., and Verte, D. (2013). Perceptual quality of neighbourhood design and feelings of unsafety. *Ageing and society*, **33**(6), 917.

Department for transport. (2015). Road Investment Safety report for 2015-16 to 2020. London. [Viewed 20th May 2017] Available in: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/408514/ris-for-2015-16-road-period-web-version.pdf

Deryol, R., and Payne, T. C. (2018). A method of identifying dark-time crime locations for street lighting purposes. *Crime prevention and community safety*, **20**(1), 47-62.

Fairclough, N. (2003). *Analysing discourse: Textual analysis for social research*. Psychology Press.

Farrall, S., Gray, E., and Jackson, J. (2007). Theorising the fear of crime: The cultural and social significance of insecurities about crime. *Experience & expression in the fear of crime working paper*, 5.

Ferraro, K. F. (1995). *Fear of crime: Interpreting victimization risk*. SUNY press.

Field, A. (2009). *Discovering statistics using IBM SPSS statistics*. sage.

Fotios, S., and Cheal, C. (2010). Road lighting for pedestrians in residential areas: choosing the optimum lamp colour characteristics. *Light & Engineering*, **18**(1), 91-100.

Fotios, S., and Cheal, C. (2013). Using obstacle detection to identify appropriate illuminances for lighting in residential roads. *Lighting Research & Technology*, **45**(3), 362-376.

Fotios, S., and Unwin, J. (2013). Relative weighting of lighting alongside other environmental features in affecting pedestrian reassurance. In: *Proceedings of the CIE Centenary Conference "Towards a New Century of Light"*, pp. 23-31. Sheffield.

Fotios, S., Uttley, J., and Hara, N. (2013). Critical pedestrian tasks: Using eye-tracking within a dual task paradigm. In: *Proceedings of the CIE Centenary Conference "Towards a New Century of Light"*, pp. 234-240. Sheffield.

Fotios, S., Unwin, J., and Farrall, S. (2015). Road lighting and pedestrian reassurance after dark: A review. *Lighting Research & Technology*, **47**(4), 449-469.

Fotios, S., Uttley, J., and Yang, B. (2015). Using eye-tracking to identify pedestrians' critical visual tasks. Part 2. Fixation on pedestrians. *Lighting Research & Technology*, **47**(2), 149-160.

Fotios, S., Yang, B., and Cheal, C. (2015). Effects of outdoor lighting on judgements of emotion and gaze direction. *Lighting Research & Technology*, **47**(3), 301-315.

Fotios, S., and Castleton, H. (2016). Specifying enough light to feel reassured on pedestrian footpaths. *Leukos*, **12**(4), 235-243.

Fotios, S., and Uttley, J. (2018). Illuminance required to detect a pavement obstacle of critical size. *Lighting Research & Technology*, **50**(3), 390-404.

Fotios, S. (2019) A review of design recommendations for P-class road lighting in European and CIE recommendations Part 1: Parameters for choosing a lighting class. [Viewed 13th February 2020] Available in: https://core.ac.uk/download/pdf/228166679.pdf

Fotios, S., Monteiro, A. L., and Uttley, J. (2019). Evaluation of pedestrian reassurance gained by higher illuminances in residential streets using the day–dark approach. *Lighting Research & Technology*, **51**(4), 557-575.

Fotios, S., Mao, Y., Uttley, J., and Cheal, C. (2020). Road lighting for pedestrians: Effects of luminaire position on the detection of raised and lowered trip hazards. *Lighting Research & Technology*, **52**(1), 79-93.

Foster, S., Knuiman, M., Wood, L., and Giles-Corti, B. (2013). Suburban neighbourhood design: Associations with fear of crime versus perceived crime risk. *Journal of Environmental Psychology*, **36**, 112-117.

Foster, S., Knuiman, M., Hooper, P., Christian, H., and Giles-Corti, B. (2014). Do changes in residents' fear of crime impact their walking? Longitudinal results from reside. *Preventive medicine*, **62**, 161-166.

Gabriel, U., and Greve, W. (2003). The psychology of fear of crime. Conceptual and methodological perspectives. *British Journal of Criminology*, **43**(3), 600-614.

Garofalo, J. (1981). The fear of crime: Causes and consequences. *J. Crim. L. & Criminology*, ***72***, 839.

Gray, E., Jackson, J., and Farrall, S. (2011). Feelings and functions in the fear of crime: Applying a new approach to victimisation insecurity. *The British journal of criminology*, **51**(1), 75-94.

Green, J., Perkins, C., Steinbach, R., and Edwards, P. (2015). Reduced street lighting at night and health: a rapid appraisal of public views in England and Wales. *Health & place*, **34**, 171-180.

Haans, A., and De Kort, Y. A. (2012). Light distribution in dynamic street lighting: Two experimental studies on its effects on perceived safety, prospect, concealment, and escape. *Journal of Environmental Psychology*, **32**(4), 342-352.

Halliday, M., Matthiessen, C. M., & Matthiessen, C. (2014). *An introduction to functional grammar*. Routledge.

Hanslmaier, M. (2013). Crime, fear and subjective well-being: How victimization and street crime affect fear and life satisfaction. *European Journal of Criminology*, **10**(5), 515-533.

Hardyns, W., Pauwels, L. J., and Heylen, B. (2018). Within-individual change in social support, perceived collective efficacy, perceived disorder and fear of crime: Results from a two-wave panel study. *The British Journal of Criminology*, **58**(5), 1254-1270.

Hassinger, J. (1985). Fear of crime in public environments. *Journal of Architectural and Planning Research*, 289-300.

Heit, E. (1997). Knowledge and concept learning. *Knowledge, concepts, and categories*, 7-41.

Herbert, D., and Davidson, N. (1994). Modifying the built environment: the impact of improved street lighting. *Geoforum*, **25**(3), 339-350

Hinkle, J. C. (2015). Emotional fear of crime vs. perceived safety and risk: Implications for measuring "fear" and testing the broken windows thesis. *American Journal of Criminal Justice*, **40**(1), 147-168.

Home Office (1989). Report of the Working Group on the Fear of Crime. *Standing Conference on Crime Prevention*.

Hutcheson, G. D., and Sofroniou, N. (1999). *The multivariate social scientist: Introductory statistics using generalized linear models.* Sage.

Jackson, J. (2005). Validating new measures of the fear of crime. *International Journal of Social Research Methodology*, **8**(4), 297-315.

Jackson, J., and Stafford, M. (2009). Public health and fear of crime: A prospective cohort study. *The British Journal of Criminology*, **49**(6), 832-847.

Kelling, G. L., and Wilson, J. Q. (1982). Broken windows. *Atlantic monthly*, *249*(3), 29-38.

Kent, M.G., Fotios, S. and Cheung, T., 2019. Stimulus range bias leads to different settings when using luminance adjustment to evaluate discomfort due to glare. *Building and Environment*, *153*, 281-287.

Killias, M. (1990). Vulnerability: Towards a better understanding of a key variable in the genesis of fear of crime. *Violence and victims*, **5**(2), 97-108.

Klama, E. K., and Egan, V. (2011). The Big-Five, sense of control, mental health and fear of crime as contributory factors to attitudes towards punishment. *Personality and individual differences*, **51**(5), 613-617.

Knight, C. (2010). Field surveys of the effect of lamp spectrum on the perception of safety and comfort at night. *Lighting Research & Technology*, **42**(3), 313-329.

LaGrange, R. L., and Ferraro, K. F. (1989). Assessing age and gender differences in perceived risk and fear of crime. *Criminology*, *27*(4), 697-720.

Lai, Y. L., Ren, L., and Greenleaf, R. (2017). Residence-based fear of crime: A routine activities approach. *International journal of offender therapy and comparative criminology*, **61**(9), 1011-1037.

Lee, M. (2001). The 'fear of crime' and governance: a genealogy of the concept of 'fear of crime' and its imagined subjects. *Theoretical Criminology*, **5**(4), 467-485.

Lee, J. S., Park, S., and Jung, S. (2016). Effect of crime prevention through environmental design (CPTED) measures on active living and fear of crime. *Sustainability*, ***8***(9), 872.

Lin, E. Y., Witten, K., Oliver, M., Carroll, P., Asiasiga, L., Badland, H., and Parker, K. (2017). Social and built-environment factors related to children's independent mobility: the importance of neighbourhood cohesion and connectedness. *Health & place*, **46**, 107-113.

Lindelöw, D., Svensson, Å., Brundell-Freij, K., and Hiselius, L. W. (2017). Satisfaction or compensation? The interaction between walking preferences and neighbourhood design. *Transportation research part D: transport and environment*, **50**, 520-532.

Loewen, L. J., Steel, G. D., and Suedfeld, P. (1993). *Perceived safety from crime in the urban environment. Journal of environmental psychology*, **13**(4), 323-331.

Lorenc, T., et al. (2013). Fear of crime and the environment: systematic review of UK qualitative evidence. *BMC public health*, **13**(1), 496.

Macassa, G., Winersjö, R., Wijk, K., McGrath, C., Ahmadi, N., and Soares, J. (2017). Fear of crime and its relationship to self-reported health and stress among men. *Journal of public health research*, **6**(3).

Maslow, A. H. (1943). A theory of human motivation. *Psychological review*, 50(4), 370-396.

Mattoni, B., Burattini, C., Bisegna, F., and Fotios, S. (2017, June). The pedestrian's perspective: How do illuminance variations affect reassurance?. In: *2017 IEEE International Conference on Environment and Electrical Engineering and 2017 IEEE Industrial and Commercial Power Systems Europe,* EEEIC/I&CPS Europe, 1-5.

Maxfield, M. G. (1984). Fear of Crime in England and Wales: *Home Office Research Study No. 78*.

McCormick, J. G., and Holland, S. M. (2015). Strategies in use to reduce incivilities, provide security and reduce crime in urban parks. *Security journal*, **28**(4), 374-391.

McIlveen, R. and Gross, R. (1998). *Developmental Psychology*. Psychology Press.

Meade, A. W., and Craig, S. B. (2012). Identifying careless responses in survey data. *Psychological methods*, 17(3), 437.

Mesch, G. S. (2000). Perceptions of risk, lifestyle activities, and fear of crime. *Deviant Behavior*, **21**(1), 47-62.

Michaelian, K. (2016). Confabulating, misremembering, relearning: The simulation theory of memory and unsuccessful remembering. *Frontiers in Psychology*, 7, 1857.

Miller, D.C. and Salkind, N.J. (2002). Guides to Methods and Techniques of Collecting Data in Library, Field, and Laboratory Settings: Social Science Data Libraries and Research Centers. In: Handbook of Research Design & Social Measurement, 6th ed. Thousand Oaks, CA: SAGE Publications, Inc. pp. 198-201.

Nair G., Ditton J. and Phillips S. (1993). Environmental improvements and the fear of crime: The sad case of the ‘pond’ area in Glasgow. *British Journal of Criminology,* **33**(4): 555-561.

Nasar, J. L., and Fisher, B. (1993). ‘Hot spots’ of fear and crime: A multi-method investigation. *Journal of environmental psychology*, **13**(3), 187-206.

Nasar, J. L., and Bokharaei, S. (2017). Impressions of lighting in public squares after dark. *Environment and Behavior*, **49**(3), 227-254.

Narendran, N., Freyssinier, J. P., and Zhu, Y. (2016). Energy and user acceptability benefits of improved illuminance uniformity in parking lot illumination. *Lighting Research & Technology*, **48**(7), 789-809.

Newman, O. (1975) Design guidelines for creating Defensible space. *National institute of law enforcement assistance administration*. United Sates Dep. Of Justice.

OED online., (©2015). *Oxford: Oxford University Press*. [Viewed 13 February 2021). Available from: http://www.oed.com

Ortony, A., Clore, G. L., and Collins, A. (1988). *The cognitive structure of emotions Cambridge*. UK: Cambridge University Press9.

Painter, K. (1996). The influence of street lighting improvements on crime, fear and pedestrian street use, after dark. *Landscape and urban planning*, **35**(2-3), 193-201.

Painter, K., and Farrington, D. P. (1999). Street lighting and crime: diffusion of benefits in the Stoke-on-Trent project. *Surveillance of public space: CCTV, street lighting and crime prevention*, **10**, 77-122.

Pease, K. (1999). A review of street lighting evaluations: Crime reduction effects. *Crime prevention studies*, **10**(1), 47-76.

Peña-García, A., Hurtado, A., and Aguilar-Luzón, M. C. (2016). Considerations about the impact of public lighting on pedestrians' perception of safety and well-being. *Safety science*, **89**, 315-318.

Piroozfar, P., Farr, E. R., Aboagye-Nimo, E., and Osei-Berchie, J. (2019). Crime prevention in urban spaces through environmental design: a critical UK perspective. *Cities*, **95**, 102411.

Piscitelli, A., and Perrella, A. M. (2017). Fear of crime and participation in associational life. *The Social Science Journal*, **54**(2), 179-190.

Poulton, E. C. (1977). Quantitative subjective assessments are almost always biased, sometimes completely misleading. *British Journal of Psychology*, **68**(4), 409-425.

Rader, N. E. (2004). The threat of victimization: A theoretical reconceptualization of fear of crime. *Sociological Spectrum*, **24**(6), 689-704.

Rader, N. E., May, D. C., and Goodrum, S. (2007). An empirical assessment of the "threat of victimization:" Considering fear of crime, perceived risk, avoidance, and defensive behaviors. *Sociological Spectrum*, **27**(5), 475-505.

Rader, N. E., Cossman, J. S., and Porter, J. R. (2012). Fear of crime and vulnerability: Using a national sample of Americans to examine two competing paradigms. *Journal of Criminal Justice*, **40**(2), 134-141.

Rader, N. (2017). Fear of Crime. *Oxford Research Encyclopedia of Criminology*. [Viewed 14 February 2021] available from: https://oxfordre.com/criminology/view/10.1093/acrefore/9780190264079.001.0001/acrefore-9780190264079-e-10.

Rea, M.S., Bullough, J.D., and Brons, J.A. (2017). Parking lot lighting based upon predictions of scene brightness and personal safety. *Lighting Research & Technology*, **49**(3): 293-304.

Roman, C. G., and Chalfin, A. (2008). Fear of walking outdoors: a multilevel ecologic analysis of crime and disorder. *American journal of preventive medicine*, **34**(4), 306-312.

Rühs, F., Greve, W., and Kappes, C. (2017). Coping with criminal victimization and fear of crime: The protective role of accommodative self-regulation. *Legal and criminological psychology*, **22**(2), 359-377.

Salkind, N. J. 2010, *Encyclopedia of research design*, vol. 0, SAGE Publications, Inc., Thousand Oaks, CA, [Accessed 15 May 2021], doi: 10.4135/9781412961288.

Sargeant, E., Liu, Y., St John, N., Fong Hong, N., Huu, T., Chen, J., and Mazerolle, L. (2017). Social capital and fear of crime in Brisbane. *Journal of Sociology*, **53**(3), 637-652.

Scarborough, B. K., Like-Haislip, T.Z., Novak, K. J., Lucas, W. L., and Alarid, L. F. (2010). "Assessing the relationship between individual characteristics, neighborhood context, and fear of crime." *Journal of criminal justice,* **38**(4), 819-826.

Schnell, R., and Noack, M. (2016). Reliability and stability of the standard fear of crime indicator in a national panel over 14 years. *Survey Research Methods*, 10(3), 253-265.

Sheffield City Region (2017). *Transport Strategy 2018-2040*. Sheffield: November 2017.

Singer, A. J., Chouhy, C., Lehmann, P. S., Walzak, J. N., Gertz, M., and Biglin, S. (2019). Victimization, fear of crime, and trust in criminal justice institutions: A cross-national analysis. *Crime & Delinquency*, **65**(6), 822-844.

Smith, L. B., & Samuelson, L. K. (1997). Perceiving and remembering: Category stability, variability and development. In Lamberts, K. and Shanks, D. R. (Ed). *Knowledge, concepts and categories*. pp. 161-195.

Stafford, M., Chandola, T., and Marmot, M. (2007). Association between fear of crime and mental health and physical functioning. *American journal of public health*, **97**(11), 2076-2081.

Steidle, A., and Werth, L. (2014). In the spotlight: Brightness increases self-awareness and reflective self-regulation. *Journal of Environmental Psychology*, **39**, 40-50.

Uttley, J. (2015) *Investigating the visual tasks of pedestrians and how one of these tasks, obstacle detection, is influenced by lighting*. Ph.D. thesis, University of Sheffield. [Viewed 13 February 2021]. Available from: http://etheses.whiterose.ac.uk/12450/

Uttley, J., Fotios, S., and Cheal, C. (2017). Effect of illuminance and spectrum on peripheral obstacle detection by pedestrians. *Lighting Research & Technology*, **49**(2), 211-227.

Valente, R., Pertegas, S. V., and Olmos, J. G. (2019). A structural equation model estimation of the role of social vulnerability as a predictor of people's feelings of unsafety. *Social Indicators Research*, **143**(2), 433-449.

Valera, S., and Guàrdia, J. (2014). Perceived insecurity and fear of crime in a city with low-crime rates. *Journal of environmental psychology*, **38**, 195-205

van Rijswijk, L., Rooks, G., and Haans, A. (2016). Safety in the eye of the beholder: Individual susceptibility to safety-related characteristics of nocturnal urban scenes. *Journal of Environmental Psychology*, **45**, 103-115.

van Rijswijk, L., and Haans, A. (2018). Illuminating for safety: Investigating the role of lighting appraisals on the perception of safety in the urban environment. *Environment and behavior*, **50**(8), 889-912.

Vauclair, C. M., and Bratanova, B. (2017). Income inequality and fear of crime across the European region. *European Journal of Criminology*, **14**(2), 221-241.

Vogt, W. P., Gardner, D. C., and Haeffele, L. M. (2012). *When to use what research design.* Guilford Press.

Welsh, B. C., and Farrington, D. P. (2008). Effects of improved street lighting on crime. *Campbell systematic reviews*, 4(1), 1-51.

Woods, C. M. (2006). Careless responding to reverse-worded items: Implications for confirmatory factor analysis. *Journal of Psychopathology and Behavioral Assessment*, **28**(3), 186.

Wyant, B. R. (2008). Multilevel impacts of perceived incivilities and perceptions of crime risk on fear of crime: Isolating endogenous impacts. *Journal of research in crime and delinquency*, **45**(1), 39-64.

Yao, Q., Wang, H., Uttley, J., and Zhuang, X. (2018). Illuminance reconstruction of road lighting in urban areas for efficient and healthy lighting performance evaluation. *Applied Sciences*, **8**(9), 1646.

Yuan, Y., and McNeeley, S. (2016). Reactions to crime: A multilevel analysis of fear of crime and defensive and participatory behavior. *Journal of Crime and Justice*, **39**(4), 455-472.